FISCAL YEAR 1990 DEPARTMENT OF ENERGY AUTHORIZATION
(Transportation Programs)

HEARING

BEFORE THE

SUBCOMMITTEE ON TRANSPORTATION, AVIATION AND MATERIALS

OF THE

COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY U.S. HOUSE OF REPRESENTATIVES

ONE HUNDRED FIRST CONGRESS

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MARCH 8, 1989

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FISCAL YEAR 1990 DEPARTMENT OF ENERGY AUTHORIZATION

(Transportation Programs)

WEDNESDAY, MARCH 8, 1989

U.S. HOUSE OF REPRESENTATIVES,
COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY,
SUBCOMMITTEE ON TRANSPORTATION, AVIATION AND MATERIALS,
Washington, D. C.

The subcommittee met at 2:05 p.m in Room 2318 of the Rayburn House Office Building, the Honorable Tim Valentine, chairman of the subcommittee, presiding.

Present: Representatives Valentine, Lewis, Rohrabacher, Walker and Campbell.

Mr. VALENTINE. (presiding) We will get started, gentlemen and ladies.

Mr. Lewis is on his way, and I hope that we will be joined by other members as the afternoon moves along.

Today the Subcommittee on Transportation, Aviation and Materials will begin its yearly authorization process by hearing from the Administration and from outside witnesses on the Department of Energy's FY '90 budget request for transportation R&D.

The programs funded by this request were mandated by two pieces of legislation that originated in this committee, so we have a particular interest in the progress being made.

The budget request for FY '90 is $29.8 million, a little more than a half of what was actually appropriated last year. Unfortunately, the Administration has again repeated its recent practice of proposing to phase out large parts of the program, a short-sighted approach in my opinion.

The transportation sector of our economy accounts for over 60 percent of our petroleum consumption and constitutes a major share of the air pollution. So it makes sense to continue investing in research aimed at reducing both of these factors.

Furthermore, the future competitiveness of our automotive industry depends on advancements in propulsion, materials, and alternate fuel use, all areas where DOE, along with NASA in some cases, has done much of the front- end research.

Cutting the transportation research effort by such a large amount makes little sense at a time when our air quality is becoming an increasingly important concern and when a substantial part of our trade deficit is due to oil imports.

Today, we hope to hear from the Department as to why its leaders feel a large reduction is justified.

Also, we have a variety of other witnesses whom we have asked to comment on the DOE's proposed program. We welcome each of you here to this hearing today and look forward to your testimony.

I will recognize my esteemed colleague, Congressman Lewis.

Mr. LEWIS. Thank you, Mr. Chairman. I have a statement but I don't have much voice today. So I will submit it for the record.

Mr. VALENTINE. Without objection.

[The prepared statement of Mr. Lewis follows:]

HON. TOM LEWIS (R-FL)

OPENING STATEMENT

HEARING ON DOE TRANSPORTATION R&D

MARCH 8, 1989

THANK YOU MR. CHAIRMAN.

ONE OF THE SMALLEST FEDERAL RESEARCH PROGRAM DIRECTED TOWARD PROVIDING TECHNOLOGY FOR A MAJOR INDUSTRY IS THE DOE TRANSPORTATION RESEARCH PROGRAM.

THERE IS A ROLE FOR GOVERNMENT RESEARCH AND I BELIEVE THE DOE TRANSPORTATION RESEARCH PROGRAM IS AN EXAMPLE. THE GOALS OF IMPROVING FUEL EFFICIENCY BY 40 PERCENT AND STUDYING FUNDAMENTAL CERAMIC AND ADVANCED MATERIALS TECHNOLOGY ARE EXCELLENT AND I SUPPORT THEM 100 PERCENT.

THE CONTROVERSY COMES IN DETERMINING THE RESEARCH MOST APPROPRIATE FOR GOVERNMENT. THIS BATTLE IS FOUGHT ANNUALLY BETWEEN THE ADMINISTRATION AND CONGRESS. THIS HAS SEVERELY CRIPPLED LONG-RANGE PLANNING ON THE PART OF BOTH THE CONTRACTORS AND THE DEPARTMENT OF ENERGY. I HOPE THAT THIS YEAR WILL BE DIFFERENT AND THAT WE CAN PASS A MULTI YEAR AUTHORIZATION.

I BELIEVE THAT WITH A 3 YEAR TO 5 YEAR COMMITMENT ON THE PART OF CONGRESS THE LONG-RANGE PRODUCTIVITY IN THE DOE TRANSPORTATION PROGRAM WILL IMPROVE. IN FACT, IT MAY BE THE ONLY HOPE WE HAVE OF GETTING U.S. TECHNOLOGY IN MATERIALS, GAS TURBINE ENGINES AND ELECTRIC VEHICLES AHEAD OF FOREIGN COMPETITION.

IF MANY OF THE RESEARCH PROJECTS UNDERWAY AT DOE ARE SUCCESSFUL, IT MAY BE ENOUGH TO TURN THE TIDE THAT WOULD EVENTUALLY PLACE THE U.S. AUTOMOTIVE INDUSTRY NUMBER ONE WORLDWIDE.

I SHOULD POINT OUT THAT I ALSO SUPPORT DOE'S EFFORTS TO END FUNDING FOR THE STIRLING ENGINE PROGRAM. THIS IS A PROJECT THAT DOES NOT BELONG IN THE TRANSPORTATION RESEARCH PROGRAM.

I HOPE TODAY'S HEARING WILL PROVIDE US WITH INFORMATION ON HOW TO ENHANCE THE U.S. AUTOMOTIVE INDUSTRY THROUGH THE DOE TRANSPORTATION RESEARCH.

THANK YOU MR. CHAIRMAN.

Mr. VALENTINE. The first panel consists of Dr. John R. Berg, Assistant Secretary, Conservation and Renewable Energy, U.S. Department of Energy, Washington, D.C.

We are glad to have you here, Doctor. You may summarize your remarks. Your statement will appear in the record in toto. Summarize it or proceed as you deem appropriate.

STATEMENT OF DR. JOHN R. BERG, ASSISTANT SECRETARY, CONSERVATION AND RENEWABLE ENERGY, U.S. DEPARTMENT OF ENERGY, WASHINGTON, D.C.; ACCOMPANIED BY MR. ALLAN STREB, DEPUTY ASSISTANT SECRETARY FOR CONSERVATION

Dr. BERG. Thank you very much, Mr. Chairman. I would certainly appreciate having it submitted for the record. I have a quick summary to make.

I am accompanied today by Mr. Allan Streb, Deputy Assistant Secretary for Conservation.

We appreciate this opportunity to appear before you today to provide the information on our fiscal year 1990 budget request for the Department of Energy's Energy Conservation Research and Development Program.

The budget for this program is consistent with and supports the goals of the nation's energy policies and is responsive to the Administration and Congressional goals of a deficit reduction.

We have request $29.7 million for the transportation programs. Last year our request was 28.4 million.

This budget was developed based on our multi-year program plan for our conservation research and development programs. The approach we used was to set goals for each program and then carefully develop a strategy to accomplish each goal. Industry determined their needs and priorities.

In general, the goal of the transportation program is to improve the efficiency with which this sector of the economy uses petroleum and to enhance the flexibility of fuel use options and transportation-related technologies.

To accomplish this goal, the multi-year plan provides prioritization of our research needs. Admittedly, the budget request to implement these plans is not a generous one, but it is sufficient and is within the current Federal budget limitations.

We concentrate our efforts on the highest priority research to address the most critical scientific and technological issues. We believe it will provide an effective program that will accomplish our program goals. We also continue to do planning and dissemination of the results of our programs and collaboration with the private sector in the forms of cost sharing and technology transfer.

The research sponsored by the Federal Government and private companies is now bearing fruit in better materials and improved components and systems designs which will increase energy efficiency both as to its use and to make alternative fuel use both reliable and economically attractive.

I would like to mention a few of the advances that were accomplished during 1988 in our automotive gas turbine program.

We completed the first phase specifications and procurement process for improved ceramic components for GM, Allison, and Garrett.

In our heavy duty transport technology we completed the fabrication and testing of a single cylinder, low heat rejection, adiabatic engine with hybrid liquid and solid phase lubrication systems with Detroit Diesel. Coatings and ceramic productions are already being utilized by diesel manufacturers in current engines.

In our alternative fuels utilization area, we have completed the establishment of a final methanol fuel free operation at Oak Ridge National Laboratory with 10 Buick Regal vehicles. Our total fleet now being evaluated consists of 10 Chevrolet Citations at Lawrence Berkeley Laboratory, 10 General Motors S-10 pickups at Argonne, 10 Ford Crown Victorias at Argonne National Laboratory, and the 10 Buick Regals at Oak Ridge.

In the electric and hybrid vehicle area, we initiated testing of the ETX-II electric propulsion system test bed vehicle with a Powerplex advanced sodium-sulfur battery. This is the first time in the United States an electric vehicle has been powered by a sodium-sulfur battery.

We completed development under a shared contract with Johnson Controls of an inexpensive device which prevents the battery case from rupturing in the event of ignition of the gases within the cell during the charging or operation of an electric vehicle.

In our technology assessment and transfer area, we co- sponsored the Methanol Marathon, a competition which is being held in the spring of 1989 in which 15 teams of college and university students will design systems and convert new cars to operate on a blend of methanol and hydrocarbons and then participate in a four-day 900-mile road rally.

General Motors has provided vehicles for technical support at no cost to the schools.

In the advanced materials development area, we completed development under a cost shared contract for a transformation toughened zirconium ceramic material, which improved and strengthened resistance to wear and corrosion. Some of the fallouts from this work are already being marketed by Norton.

As a matter of fact, Norton and Torrington are right now producing ball bearings out of ceramics for use in many applications. These ball bearings have a lower coefficient of friction, can operate at higher temperature and are lighter weight than steel bearings are.

Some of the offshoots of this means there is less inertia, therefore less energy wasted in the raceway.

In our high temperature materials laboratory at Oak Ridge we have completed the first year of operations for the maximum utilization of users, including 22 universities and 14 industry participants.

Mr. Chairman, these are just some of the accomplishments that have resulted from the research sponsored by the Federal Government and the private sector. We must continue to look to the future and pursue those activities which will expand and improve our energy use options.

The long term solution to our energy problems is through improved technology. We must improve both utilization, efficiency, and the capability to use alternative fuels, and the only way to improve technology is through research, and it is in this area of research that we think there are some crucial decisions to be made, and this is where the Congress and the Department of Energy must work together.

Together, we need to be assured that every dollar appropriated for research and development is spent productively. If we are going to spend more than the President requests, then we should maintain a course which the conservation program and the input from industry and academia is now following and to continue to support justified work that actually advances the national energy, environmental, and security interests which will contribute to the U.S. productivity competitiveness.

If we do that, we can turn the budget reductions that we face into an opportunity to bring more discipline and higher quality work to our research programs in the most cost efficient and cost effective manner.

It is important that the decisions that we make move the nation towards a greater energy efficiency.

We appreciate working with this committee and their ability to realize that the priority goals that we have set are on the right track.

Mr. Chairman, we appreciate the opportunity to appear before you today, and we will be happy to answer any questions you may have.

[The prepared statement of Dr. Berg follows.]

STATEMENT OF

DR. JOHN R. BERG

ASSISTANT SECRETARY

CONSERVATION AND RENEWABLE ENERGY

BEFORE THE

COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

SUBCOMMITTEE ON TRANSPORTATION, AVIATION, AND MATERIALS

U.S. HOUSE OF REPRESENTATIVES

MARCH 8, 1989

Mr. Chairman and Members of the Subcommittee, I appreciate the opportunity to appear before you today and provide information on our FY 1990 budget request for the Department's transportation energy conservation research and development program.

TRANSPORTATION RELATED GOALS

The transportation sector used 21.8 quads of energy in 1988, 97 percent of which was in the form of oil. Transportation petroleum consumption was approximately 10 million barrels per day, which accounted for 63 percent of all petroleum consumed and 27 percent of all energy used in the United States. The transportation sector in 1988 used 23 percent more oil than the United States produced. This means that the nation needs to import oil to feed its transportation demands even if every other end use sector eliminated its use of oil. In fact, the amount of oil consumed by the transportation sector has exceeded U.S. oil production every year since 1975.

In spite of the substantial improvement in efficiency in autos, trucks and aircraft, since 1973, the amount of petroleum used each day by the transportation sector in the United States is more than one million barrels higher than in 1973. Whereas every other sector has decreased its use and its reliance on oil since 1973, the transportation sector's use has increased and its reliance remained near 100 percent. There is a very pressing need for the transportation sector to become less reliant on oil which could be achieved by building flexibility into the fuel choice of individual vehicle owners.

The role of the Federal government is critical in the development of energy efficient and fuel flexible transportation technologies that can be employed in the late 1990s and after the turn of the century to make the U.S. transportation sector more efficient, competitive and less dependent on petroleum. The private sector is not ready to pursue, on its own, some of the most promising long-run technology options because of the high risks involved. The public-at-large also stands to gain a great deal from the success of our R&D. If our research on materials or other technologies could reduce the initial cost of autos by only one percent, the annual savings would amount to one billion dollars. Similarly, if our research resulted in just a one mile-per-gallon improvement in autos, the annual savings could be almost $5 billion. Both of these potential annual savings to auto users, are very large compared to the small annual expenditures on DOE's transportation R&D.

A very important side benefit of the transportation conservation technologies is their potential for positive direct reduction in air pollution. Every percent of improvement in fuel economy brings about a percent of reduction in carbon dioxide emissions which, may contribute to suspected global warming. Furthermore, the gas turbine engine and the electric vehicle would reduce the release of pollutants that cause urban air quality problems. They would accomplish this without the use of expensive catalytic converters.

FY 1990 BUDGET

The FY 1990 budget request of $29.7 million in the transportation area is consistent with the goals and objectives of national energy policy and is fully responsive to the Administration and Congressional goals of deficit reduction. This budget request was developed based on our multi-year program plan for the conservation research and development programs. The approach we used is to set goals for the programs and then carefully develop a peer-reviewed plan to accomplish the goals. The goals of the transportation programs are to improve the efficiency with which this sector of the economy uses petroleum and to enhance the flexibility of fuel use options and transportation-related technologies.

The funding requested will be used to continue research and development to: (a) develop scientific knowledge and proofs-of-concepts for advanced engine technologies that demonstrate at least 30 percent improvement in fuel economy over conventional current production heat engines under similar vehicle weight to horsepower conditions, that have the capability to meet emissions, safety, and noise standards, and which have the potential for competitive initial and life-cycle costs when in production; (b) overcome key technological barriers, particularly relating to energy storage, to private sector development of electric and hybrid vehicles; (c) establish a fundamental ceramic and advanced materials technology base to support the U.S. heat engine industry; and

(d) encourage the utilization of alternative fuels by providing industry with fundamental scientific information on the properties and behavioral characteristics of alternative transportation fuels when used in contemporary and advanced engines.

I would now like to describe our progress in meeting these goals and objectives, our planned activities during FY 1989, and our budget request for FY 1990 for each of the programs under your jurisdiction.

VEHICLE PROPULSION R&D

For the past several years, the focus of the Vehicle Propulsion R&D program has been on development of advanced automotive gas turbine and Stirling engines and heavy duty transport uncooled, minimum friction diesel engines with integrated waste heat recovery. These engine projects were designed to implement provisions of the Automotive Propulsion Research and Development Act of 1978 (Title III of P.L. 95-238) by proving high-risk engine design concepts and demonstrating that obstacles to commercialization in the form of technology barriers can be overcome with high energy saving potentials.

The objectives of the Advanced Turbine Technology Applications Program (ATTAP), a follow-on to the Automotive Gas Turbine Program, are to establish the reliability of ceramic component designs and materials in automotive gas turbines, expand the experimental database in the operating environment, and complete the development of analytical tools needed to support industry in their successful application to long-life turbine engines. Both gas turbine engine contractors, Allison Gas Turbine Division of General Motors and Garrett Auxiliary Power Division of Allied-Signal Aerospace Company, are currently continuing in the role of system integrators and will evaluate developed components in the existing engine testbeds. A detailed materials assessment of all available ceramic component suppliers has been completed, and characterization and durability were determined for promising high temperature ceramic materials. New designs and requirements for ceramic component fabrication were initiated, and engine and component test rigs have been analyzed and updated. Durability characterization of candidate structural ceramic materials will continue. Subcontracts for fabrication of the first advanced ceramic components have been initiated with United States suppliers. Deliveries of these components are scheduled to begin in late 1989, with evaluations continuing in 1990 in test rigs and engine testbeds. In FY 1990, $5.0 million is requested to continue development and evaluation of high temperature structural ceramic components, including the rig testing of turbine rotors, with a single industry contractor as the system integrator.

The Automotive Stirling Engine (ASE) technology program has been centered on a proof-of-concept engine development contract awarded to an industry team led by Mechanical Technology Incorporated. To date over 19,000 hours of performance testing have been completed on Mod I experimental engines, confirming the predicted performance goals for this design. Performance characterization of the upgraded Mod I (Mod IA) engine, which operates at a higher heater-head temperature, has also been completed. The proof-of-concept program will be concluded this year with the demonstration of program goals in Mod II engines both on a dynamometer and in a United States Postal Service (USPS) long life vehicle. Uncosted FY 1988 appropriations are being used to complete these activities. The objective of the FY 1989 effort is to exploit the technology developed in the engine development program and extend it to promising near-term applications such as vans and light trucks. The Mod I engine-powered D-150 pickup truck will be used to demonstrate low emission capabilities in Colorado. Development of the Mod II engine-powered postal van will be continued, to improve life and reliability, and will then be evaluated in actual operational use, first by the United States Air Force and then by the USPS. After this, the Federal role should be complete, and no funds are being requested for Stirling engine R&D in FY 1990.

The Heavy Duty Transport (HDT) technology program focuses on establishing the technology base for future development of advanced adiabatic (low heat rejection) diesel engines. By eliminating or significantly reducing the size of the engine block cooling system and recovering the increased exhaust energy, the diesel engine system can be made much more efficient and fuel flexible. The program consists of four R&D areas necessary for this development: (1) thermal insulation, (2) lubrication, friction, and wear, (3) advanced thermomechanical systems, and (4) high temperature combustion and emissions. Single-cylinder test engines are used in the development of the basic technologies and components. In the thermal insulation area, the feasibility of fabricating thick ceramic thermal barrier coatings on combustion chamber components has been demonstrated by both Cummins and Caterpillar. In FY 1989 the work will be expanded to include 300 hours of tests and the measurement of emissions. This program will be completed in early FY 1990. The major activity in the lubrication, friction, and wear area is the development of a high temperature liquid lubricant which, if successful, will greatly extend the capability to develop more fuel efficient engines with reduced oil consumption, while also providing greater power density. It should be pointed out that a large percentage of particulate formation in heavy duty diesel engines comes from oil consumption in the combustion chamber. This activity is continuing in FY 1989 at Cummins Engine Co. and AKZO Chemical Co. At the University of Michigan, investigations are continuing on friction and wear with ceramic wear point materials in the valve train of a diesel engine to further our understanding of lubricated ceramic and metal surface interactions under engine conditions.

In the area of advanced thermomechanical systems, the investigation of solid and vapor phase lubrication of the upper cylinder with ceramic moving parts and an electro-hydraulic fuel injection system has been completed with single-cylinder engine testing. A major new effort in FY 1989 is the innovative piston-liner and applied tribology program for the development of high temperature components incorporating design features which comply with the very stringent 1994 emissions regulations. In the high temperature combustion and emissions area, investigations will continue on the difficult problem of heat transfer in an insulated engine. Also in FY 1989 a promising nitrogen-oxides reducing aftertreatment concept called RAPRENOX, developed at the Sandia National Laboratory, will be evaluated for engine use. Engine combustion parameters optimized to reduce NOx levels invariably increase particulate emissions. Laboratory tests of the RAPRENOX system indicate that a 95 percent NOx reduction is achievable regardless of particulate level. Successful engine evaluation of RAPRENOX would then allow us to focus on particulate reduction. A total of $2.2 million has been requested in FY 1990 to continue investigations of sliding seal materials, development of thick thermal barrier coatings, and development of advanced in-cylinder components.

ALTERNATIVE FUELS UTILIZATION

The focus of the Alternative Fuels Utilization program is to foster the use of nonpetroleum-based transportation fuels by establishing a technology database for both contemporary and advanced heat engines. Several efforts emphasize the use of synthetic fuels derived from heavy oil and tar sands (near-term to mid-term options) as well as fuels derived from oil shale and coal (longer range options). Other fuels options receiving attention in FY 1989 are methanol and, to a limited extent, natural gas. Modest efforts in applied technology to enhance the combustion of alternative fuels are also underway. In addition to monitoring foreign and domestic activities, workshops and technical sessions are organized to facilitate technology transfer to industrial users. Assessments are conducted to consolidate new data, identify critical open issues, and plan R&D projects needed to fill gaps.

In order for the scientific community to conduct useful synfuels projects, it is necessary to have access to properly prepared test fuels. During the past several years and continuing in FY 1989 this requirement has been met through the support of a Synthetic Fuels Center at Southwest Research Institute.

The evaluation of Government fleet operations with methanol-fueled vehicles will be continued in FY 1989. Three fleets now operate at DOE laboratories and are providing industry with both technical and operational data on which to base production and marketing decisions. The methanol fleet evaluations were expanded to Hawaii last year with the support of a Hawaiian State Government fleet project. This limited support is being continued in FY 1989.

$1.3 million has been requested in FY 1990 to investigate performance, emissions, and wear with advanced and conventional engines using alternative fuels; operate a synthetic fuels test facility; and collect and analyze methanol fuel-use data from the ongoing Federal fleet evaluation project. An additional $1.5 million has been requested to start implemention of the provisions of the Alternative Motor Fuels Act of 1988, which was enacted in October 1988.

ELECTRIC AND HYBRID VEHICLE R&D

The objectives of the Electric and Hybrid Vehicle program are to: (1) conduct the research and development necessary to advance the technology to the point that transfer to the automobile industry for application-oriented R&D becomes feasible, (2) identify technology deficiencies of electric vehicles, (3) evaluate the performance characteristics of new and improved technologies to determine their potential for resolving these deficiencies, and (4) conduct engineering development of maturing technologies.

The major elements of this program are battery and propulsion system technology development. The goal of the battery program is to develop a full battery subsystem which will meet environmental, shock, and vibration conditions, and realistic electric vehicle driving profiles expected in vehicle usage. In FY 1989 in iron-air battery technology R&D, the Westinghouse Corporation is continuing to expand cell and module developments into a full-sized vehicle subsystem. The sodium-sulfur effort is continuing with the development of the technology for electric vehicle application, based on the core technology contract with Chloride Silent Power, Ltd. Also this year, requests for proposals will be issued to seek sources for the development of sodium-metal chloride and lithium-metal sulfide battery technologies. The zinc-bromine effort at Johnson Controls, Inc., is continuing to solve electrode warpage, stack sealing, cathode activation layer, and zinc dendrites/stripping problems in order to enhance battery life and efficiency. Johnson Controls is developing an advanced lead-acid battery to improve the performance and life of a flow-by battery, meeting the mission requirements for electric vans. Finally, work will be initiated this year to incorporate the Proton Exchange Membrane (PEM) fuel cell in transportation applications.

In FY 1990, $3.5 million has been requested to continue the development of the most promising of the battery concepts. Development of sodium-sulfur battery technology, including subsystem thermal management, safety, and integration with the advanced powertrain, will continue. Integration and testing of the total zinc-bromine battery subsystems will be completed, and the battery will be evaluated in the context of the propulsion system. Development of a lithium-metal sulfide battery system with enhanced development of a thermal management system will be continued.

The electric vehicle propulsion system technology development activity addresses the components and subsystems of the entire vehicle that are required to provide controlled motive power to the wheels. Within this area, three major programs are in progress. These are: (1) the Second-Generation Single-Shaft Electric Propulsion System Technology Development Program (ETX-II), (2) the Dual-Shaft Electric Propulsion Systems Technology Development Program (DSEP), and (3) the Fuel Cell/Battery Bus System Program. Each of these programs involves advanced battery subsystems, advanced powertrains, and the development of complete, proof-of-concept propulsion systems integrated into test vehicles for evaluation.

The ETX-II program is an a.c. R&D activity focusing on the light-weight van market. Major advances from this program include: a new interior permanent magnet rear-mounted motor and transaxle, improved transistorized inverter power modules, and a multiprocessor system controller capable of regulating all of the complex electrical and mechanical functions of the vehicle. Sodium-sulfur and zinc-bromine are the primary batteries for this program. Activities for FY 1989 are: (1) to test the advanced sodium-sulfur battery built by Chloride Silent Power using the ETX-II powertrain system; (2) to test and evaluate the Powerplex sodium-sulfur battery in the ETX-II vehicle; (3) to build a second ETX-II testbed vehicle to support multiple battery testing; and (4) to design, build, and test a MOS Controlled Thyristor (MCT) inverter to supply the ETX propulsion motor. This is an advanced power device which will reduce the size, weight, and cost of the present ETX-II inverter.

The DSEP program focuses on the near-term development of an a.c. propulsion system and nickel-iron battery subsystem and light-weight van application. To date, the program has achieved the successful completion of the first testbed vehicle tests, achieving performance comparable to that of internal combustion engine-powered vehicles; the completion of the conversion of a second vehicle, dynamometer tests, and vehicle installation of the powertrain; the completion of conversion and start of subsystem installation in a third vehicle; and the completion of nickel-iron battery life tests, performance tests, and an assessment of battery system status. FY 1989 activities include: (1) completion of performance, reliability, and durability tests for the second vehicle; (2) completion of powertrain installation and subsystems for the third vehicle; (3) delivery of the second and third vehicles to DOE for independent tests and field evaluation; and (4) completion of an analysis of the DSEP vehicle/propulsion system manufacturing cost and life cycle costs.

The objective of the fuel cell/battery powered bus sytems program is to develop a methanol-fueled phosphoric acid fuel cell and battery power source in a propulsion system for a small urban bus. This cooperative program is jointly funded by DOE and the Urban Mass Transportation Administration. The program is divided into four phases: (1) proof-of-feasibility for the fuel cell/battery system, (2) proof-of-concept in a testbed bus, (3) evaluation of a testbed bus, and (4) field testing of prototype buses. Evaluation of both air-cooled phosphoric acid fuel cells and liquid-cooled systems will provide the greatest probability of success in applying fuel cell technology to transportation. Phase I contracts on both air-cooled and liquid-cooled systems, which consist of a system design and integration effort to develop the proof-of-feasibility fuel cell/battery propulsion system, will be completed at the end of FY 1989. At that time one technology will be selected for the Phase II effort. No funds have been requested in FY 1990 to continue electric vehicle propulsion systems activities since all three systems will have been advanced to the point that transfer to the automobile industry for application-oriented R&D is feasible.

In FY 1989, engineering evaluation testing will include laboratory and in-vehicle dynamometer testing at the Idaho National Engineering Laboratory of the ETX-II and second generation DSEP/TB-2 propulsion systems in testbed vehicles, and the General Motors G-Van and a Soleq EVcort with electric air conditioning. Battery laboratory characterization testing will be conducted on an improved roll-bonded nickel-cadmium battery system and on the Powerplex sodium-sulfur battery. In addition to the testing activities, research and development in support of the site operator field testing are continuing in areas of eliminating auxiliary batteries with d.c. to d.c. converters; improved data acquisition systems; and development of battery charging algorithms monitored and controlled with individual module information collected through a single wire loop system.

Technology engineering development on nickel-iron batteries is focusing on integration of nickel fiber into the nickel electrode with the objective of improving both the performance and cost of the nickel-iron battery. Nickel-cadmium battery technology development under the contract with Energy Research Corporation (ERC) has been completed. Independent test and analysis of the ERC nickel-cadmium technology will continue through FY 1989. Test results will be used to define research and development objectives for a new nickel-cadmium research contract to be awarded in early FY 1990.

In the area of site operations, operational fleet testing by 7 site operators at 16 site locations is being conducted in FY 1989 to evaluate vehicle performance and to collect engineering data on vehicles in the product improvement program. As part of the product improvement program by the Site Operators' User Task Force, Detroit Edison is continuing to road test the GM-Griffon van and is expecting to procure one or more preproduction GM G-Vans. Arizona Public Service is evaluating three Soleq d.c.-powered vehicles equipped with air conditioning, and GTE will be taking delivery of the d.c.-powered Lynx which is equipped with a three-speed transaxle automatic transmission and will be placed in service at GTE headquarters in Dallas. An outcome of the dual battery van program at Soleq should be finalized and retrofitted into a Task Force vehicle for field evaluation.

In FY 1990, $0.8 million has been requested to conduct limited laboratory characterization testing of the sodium-sulfur and zinc-bromine advanced battery systems, and to initiate in-use test and evaluations of new vehicle technologies.

ADVANCED MATERIALS DEVELOPMENT

The objective of the Advanced Materials Development program is the development of an industrial technology base required for the fabrication of reliable ceramics to be applied to advanced automotive heat engines. While this is a generic materials development program, it currently focuses specifically on structural ceramics for advanced gas turbine and diesel engines, ceramic bearings and attachments, and ceramic coatings for thermal barrier and wear applications in these engines. The work is divided into three major tasks: materials and processing, design methodology, and database and life prediction.

The materials and processing task includes four subtasks: monolithics, ceramic composites, thermal and wear coatings, and joining. The overall integrated approach is designed to: (1) develop improved starting powders with high chemical purity and controlled particle size and the needed characterization tools for fine particulates, (2) develop controlled ceramic processing procedures that eliminate the traditional sources of strength-limiting flaws and result in ceramics with improved Weibull distribution modulus, (3) develop a new class of tough ceramic composite materials with much greater resistance to brittle fracture, (4) develop durable and adherent coatings for wear resistance and thermal insulation, and (5) develop reliable joining technology for ceramic-to-ceramic and ceramic-to-metal joints.

The design methodology task is concentrated on determining analytical techniques for predicting structural ceramic mechanical behavior from mechanical properties and microstructure, tribological behavior at high temperatures, and improved methods for describing the fracture statistics of structural ceramics. Results from these investigations will provide U.S. companies with methods for optimizing mechanical properties through microstructural control, for predicting and controlling interfacial bonding and minimizing interfacial friction, and for developing a properly descriptive statistical database for structural ceramics.

The database and life prediction task is focused on the understanding and application of predictive models for structural ceramic mechanical reliability, measurement techniques for determining long-term mechanical property behavior in structural ceramics, and physical understanding of time-dependent mechanical failure. There are five subtasks in this program element: (1) structural qualification, (2) time dependent behavior, (3) environmental effects, (4) fracture mechanics, and (5) nondestructive evaluation. The approach is a coordinated effort involving many researchers working in parallel on test method development, data production, and life prediction modeling and testing. The work is coordinated continuously with related activities in the Advanced Turbine Technology Applications and the Heavy Duty Transport programs, which involve design and testing of ceramic engine components. The results from this area of research will provide U.S. companies with the tools needed for accurately predicting the mechanical reliability of ceramic heat engine components, including the effects of applied stress, time, temperature, and atmosphere on critical ceramic properties.

During FY 1989, the phased activities on existing contracts and research projects are being continued essentially in accordance with the Ceramic Technology for Advanced Heat Engines Program Plan. In materials and processing major efforts include improved processing of monolithic ceramics with the goal of developing new and improved ceramic processing methods and in-process inspections that will eliminate the sources of strength-limiting flaws in structural ceramics; application of microwave processing to ceramic materials for sintering, joining, melting, and heat treating; use of aqueous gel-casting systems for silicon nitride; facilitating the production of improved silicon carbide whiskers for fabricating stronger and tougher composites; fabrication of whisker SiAlON composites by optimized processing techniques; refinement of the near-net-shape part fabrication process of composite ceramics through injection molding; development of wear-resistant coatings for application to metallic components for low-heat loss diesel engines; and joining of ceramics.

Materials design methodology activities in FY 1989 include investigation and development of mathematical models for crack facture with realistic geometry; modeling of the performance of advanced wear-resistant coatings, ceramic composites, and newly developed high temperature liquid lubricants; and evaluation of the effects of time on the statistical distribution parameters used to describe material strength.

In the database and life prediction area, projects will be continued on the effect of the translucence of ceramics on heat transfer in a heat engine; maintenance of a comprehensive computer database containing the experimental data on properties of ceramic materials generated in all of the program efforts; life prediction, including materials selection, database and design methodology development and application of nondestructive examination, and confirmatory testing; testing of ceramic materials such as silicon nitride and advanced whisker toughened composites in a tensile mode at elevated temperatures; stress rupture and creep testing to determine room temperature and high temperature behavior of toughened ceramics;

investigations of the fracture behavior of toughened ceramics; investigations on the environmental degradation of gas turbine and diesel candidate ceramics; and detection and measurement of microscopic flaws as well as nondestructive determination of physical or mechanical properties in structural ceramics which are critical to improving and controlling the reliability of these materials in highly stressed applications such as advanced heat engines. The International Energy Agency agreement on Ceramics for Advanced Engines and Other Conservation Applications with Sweden and the Federal Republic of Germany will be continued during FY 1989. Results of the round-robin series of mechanical property measurements will be published and work on ceramic powder characterization will be continued.

In FY 1990, $10.3 million is requested to continue research projects in ceramics powder development, joining of ceramics, chemical vapor deposition coatings, toughened ceramics, ceramic composite processing, new ceramics forming and sintering techniques, and ceramic whiskers development. R&D projects in design methodology and database and life prediction will also be continued. These include advanced statistics and wear behavior of materials for insulated diesel engines, ceramic fracture behavior, cyclic fatigue failure, high temperature tensile testing, toughened ceramic life prediction and ceramic powders characterization.

HIGH TEMPERATURE MATERIALS LABORATORY

To support the advanced materials work conducted under this and other research programs, the construction of a user-oriented High Temperature Materials Laboratory (HTML) was completed early in 1987 at Oak Ridge National Laboratory. The HTML is fully operational. Both proprietary user research with full cost recovery and non-proprietary research at no cost to the user, where results are immediately available to the scientific and industrial community, are being carried out at the laboratory. In FY 1990, $2.0 million is requested to support the permanent User Center staff, which is critical to maintaining and safely operating the unique instruments and to providing the necessary strong research assistance required for the users.

TECHNOLOGY ASSESSMENT AND TRANSFER

The Technology Assessment and Transfer program centralizes cross-cutting functions such as the identification, monitoring, review, and assessment of related industry and market trends; transfer of information on technologies developed; publication of statistical compendiums; and management and planning support. In FY 1990, $1.0 million is requested to collect, analyze and present transportation and energy data, including market conditions for fuel efficient technologies; provide consistent baseline projections of the demand for transportation energy by mode for use by program managers in program planning and monitoring; and conduct transportation technology assessment and transfer activities.

PROGRAM DIRECTION

To provide the overall direction for the transportation programs, including the development of the strategy, plans, and resource requirements, and integrated program management, we are requesting $1.5 million in FY 1990.

SUMMARY

In summary, we believe the funding requested will allow DOE to accomplish the goals of the transportation program. The research sponsored by the Federal Government and private companies in the past is now bearing fruit in better materials and improved components and system designs which increase energy use efficiency and make alternative fuel use more reliable and economically competitive. Now we must look to the future and pursue those activities which will slowly but surely expand and improve our transportation options. The way out of our energy problems in the long run must be through better technology, to improve both utilization efficiency and the capability to use alternative fuels. And the only way to better technology is through research.

That concludes my testimony, Mr. Chairman. I appreciate the opportunity to appear before you today.

Mr. **Valentine**. Thank you, Doctor.

If we could restore any of the reductions made by OMB, what programs would, in your opinion, have the highest priority?

Dr. **Berg**. There are several, Mr. Chairman. The alternative fuels we would like to have—we could utilize more money—let me put it that way—in the alternative fuels area. We could use more in our AC propulsion development system.

If we had additional funds, we would do some more in the area of looking at the replacement of CFCs in the air conditioning systems for vehicles, and we would add more money back for alternative fuels and synfuels.

In addition, if we had more in the battery program, we would do some more work in the area of advanced acid batteries.

Mr. **Valentine**. With respect to the ATTAP, would the budget constraints—are those the only reason for requesting funding for only one industry contractor?

Dr. **Berg**. At the present time with the budget priorities that we have, we felt it wise to reduce it to one in order to meet obligations in other areas of research. That is correct.

Mr. **Valentine**. What would be the cost, approximately, of maintaining a two-contractor program?

Dr. **Berg**. Approximately twice what we have. However, what we would like to do is utilize what we have here and ask industry to further cost share in this. The idea that perhaps we could continue with the funds, we would request two contractors. At the present time there is a lot of fallout, as we mentioned, to these ceramics. Industry has been cost sharing on this program, as you are probably very well aware. It started out at about 6 percent. It is now up to 20 percent. But we asked 30 percent cost sharing in many of our programs, and if two industries would come up with more funding, we would think that indeed we could carry both of them rather than just going with one.

I would just like to point out a few of the applications are getting out, and I am sure that people here are going to be showing you other applications as well. It is a tremendous opportunity, and the industry has utilized developments from our program to improve further energy efficiency in other areas, whether it be in the area—for instance, the example here of a ceramic valve that is right now one that is sodium nitride made by Norton and TRW. This has been utilized in an Oldsmobile car. In fact, it ran in a Florida 500 down there just recently. It is showing extremely good potential.

The interesting thing about this is these are devices that are lighter weight, therefore less inertia. You are getting increased gas mileage because you have less material to be moving when the valves are going up and down. They are higher temperature, higher resistance, and as a consequence they last longer and are less prone to burning the valve seal.

But there are many other areas like this where our ceramics program, the program from this for the development of ceramic parts that are being utilized in the industry for other applications, everything from water pump seals by Volkswagen to the coating of the valves by Cummins and Caterpillar on their valves.

Mr. VALENTINE. Activities in the area of heavy duty diesel trucks are proposed at a level which is considerably less than FY '89. Things like high temperature lubricant development were eliminated, and so on.

Is this wise, in your opinion, Doctor, considering the contribution that large trucks make in connection the national petroleum consumption?

Dr. BERG. In this, like many other things, we had to set our priorities, and again we used the priorities that industry asked us to work on. That program is proceeding forward on those areas that industry has asked.

It did mean cutting back on some areas which, if we had further funding, we would like to see done, but at this point we are working on our high priorities, in our understanding.

Mr. VALENTINE. I know you have to make a lot of hard and difficult decisions, but can you tell us why the request for advanced materials was lower than last year—the level requested was lower than last year's level, than that which is shown in your program plan?

The FY 1989 request is 10.3 million, the FY '88, 15.3 million. The program plan for FY '90 is 15 million.

Dr. BERG. Again, sir, it is a matter of the priorities that we have and the budget we have to work with. We have to establish certain priorities and go with the ones that we feel, with industry, are the ones that are important.

I don't think anyone would object to the priorities that we set. They may object to the amount of money we are spending on them, but I don't think anyone would object to the priorities that we have established.

Mr. VALENTINE. Can you tell us why the Administration only requested development work for three batteries? If you could do it, what type of battery work would you restore, if the FY '90 budget were increased?

Dr. BERG. Again, we are working on the longer range batteries. In this case we are looking at the lithium-metal sulfide batteries, the sodium-sulfur batteries, and the zinc-bromine batteries. The other batteries, the lead-acid batteries we felt at this point are in a position where industry could take on and work with them.

True, if there were monies available, we would continue to do some further testing on the lead-acid flow-through battery, but at this point we do feel that with the funds that we have, in order to reduce the size, weight and power density, that we are better working with the three batteries that I mentioned.

Mr. VALENTINE. How far away are we from the time when it would be practical to operate a motor vehicle on the public highways with battery power?

Dr. BERG. It appears that it is getting very close. In fact, we expect there will be some G-vans made available in 1990, and it would appear that by the mid-'90s that we will see the TE-vans, and certainly after the work and the effort that has gone into the ETX vehicle with the sodium-sulfur battery, we would anticipate that by the mid-'90s there would begin to be commercially available vehicles for sale to the general public.

Mr. Valentine. You requested $425,000 for what is referred to as end-use test and evaluations of new vehicle technologies.

Is this intended as an extension of the user task force activities, or is some other program envisioned?

Dr. Berg. That is user testing, sir.

Mr. Valentine. Thank you, sir.

Mr. Lewis. Thank you, Mr. Chairman.

I noticed that the Office of Transportation initially requested $3.5 million for magnetic levitation.

What was planned for this money, and what do you envision for the outyear effort?

Dr. Berg. This was put into—on my wish list type things, but again it was in order—we feel that with the superconductivity program that it is important to go back and take a look at the original work that MIT had done on levitation of vehicles, and in the future the levitation of vehicles will be an important transportation mode, and sooner or later the Department will want to be in that area.

Mr. Lewis. Are we actively pursuing anything in this area?

Dr. Berg. We are not actively pursuing it at the present time. We are actively pursuing other areas of superconductivity, but not for levitation vehicles.

Mr. Lewis. Doesn't magnetic levitation appear to be the best type of locomotion at this point in time?

Dr. Berg. It appears that it could be one. NASA, as you could be aware, has been doing some work in this area.

Mr. Lewis. And you are not going to get into it now?

Dr. Berg. Not with the other priorities and the size of the budget, no, sir.

Mr. Lewis. How are we standing with the Japanese as far as the ceramics?

I noticed you were discussing about the valve there.

How do we stand with them at this point in time?

It is my understanding they have an operable engine.

Dr. Berg. As far as technology is concerned, we figure we are in a good horse race. In some areas we may be ahead. In the area of the fiber work, in the production of powders, some of these we think perhaps the Japanese are ahead.

But it is, as I mentioned, a horse race, involving not only Japan and the United States but other countries as well are working very diligently towards the applications utilizing ceramics.

Mr. Lewis. Are you satisfied that the private sector is really putting forth their best foot in the interest of synthetic fuels?

Dr. Berg. As far as synthetic fuels are concerned, in our renewable area, we are working on a number of areas there, in the area of biofuels, and we are working with Mobil and some of the other people that are now beginning to show an interest in this area.

As you are aware, in the conservation area we have the Southwest Research Institute, where we are doing some supply pipelines in the area of synthetic fuels for some other types of things.

I think with the emphasis in many areas on the reduction of pollution and the like, we are going to see a greater emphasis in this area. I would like to see industry have a greater involvement in it, though.

Mr. LEWIS. Do you really feel that the number of programs that you have moving in the Department—in your requested budget that you have established priorities on, are they for real or are they smoke in mirrors, just to appear like you are busy?

Dr. BERG. These are for real, sir. These are things that are being developed and are excellent examples of utilization of Federal funds and private industry dollars going together to get something that the American taxpayer is going to be and is deriving benefit from today.

Mr. LEWIS. The reason I raised the question was not to be facetious, but I have been sitting here for six years and we are still working on the same programs, still requesting approximately the same number of dollars, prioritizing essentially the same programs, and we are always on the threshold but we are never there.

Can you respond to that comment?

Dr. BERG. I have only been in the Department now since '86, and I have seen some programs come. I have seen some programs go.

Certainly, there are some of these programs that have continued to be funded that are reaching and stretching, the electric vehicle for one, which is in the process of finally coming to fruition.

I think a number of these programs took longer than the Department anticipated. I think they took longer than perhaps maybe people in industry thought would be logical.

However, if you take a look at the advances that we have made in such things as the automotive gas turbine and some of these other programs, I think that they are showing extremely good, solid advancements and are getting closer and closer to being realities.

Mr. LEWIS. Well, I just look at the methanol program that has been worked on. I am not sure that we really put our best foot forward on that program. It seems to me we have been working on methanol propulsion for a number of years, and it is always just getting better. Hydrogen is another area we have been working in.

I just wonder if we are prioritizing and putting all of our money in the proper channels rather than keeping a lot of programs going.

Shouldn't we be looking at prioritizing one, two, three, or four and moving strongly in those directions?

Dr. BERG. Some of the programs that you mentioned are ones that we would fund. Some of them are ones that we wouldn't fund, and this subcommittee has asked for funding on some of them and others have, and some of these are the ones that we keep dropping off every year. We keep coming in and asking for low priority, lower dollars, and they drop off in some of these areas.

The methanol vehicle program happens to be one now that is about to be commercially available. Obviously, California is going to be purchasing 2800 vehicles, methanol-fueled vehicles, and Ford at the end of '92 will be offering for sale a flexible fuel vehicle that can run on either gasoline, methanol or a combination thereof.

Much of the methanol, for instance, had been a cost versus the cost of gasoline. That has been one of the problems with many of our alternative fuel programs, is the actual cost not of the product itself, but of the infrastructure in order to set it up.

Certainly, things like hydrogen are not a primary fuel source. It has to take energy to derive hydrogen. It has a niche market perhaps, but it is not one that we would classify that has a large potential, for instance, say like the methanol program.

Mr. **Lewis.** I understand the rationale and the reasons for that. I personally get very concerned. Over a period now of about 15 years, looking at the private sector as well as the governmental sector working toward research in the area of alternative fuels, I just don't think they work very hard at it, frankly.

The cost of a particular fuel like methanol, I think if you are looking for an alternative fuel, that should not be one of the criteria that slows down your progress on research because some day we may have another OPEC cutoff and it won't make any difference how much it costs to get something to drive. People are going to pay for it, and in particular industry if they want to move product from one coast to the other.

I sometimes think that your organization is a dog chasing its tail. We will just keep working on this project, keep it on the middle burner and let it run until we get something, but it is not something you are working that hard on.

And I am not shooting at you or anybody else. I am shooting at everybody.

I think the same thing is true with gasohol.

You know, in Brazil 95 percent of the vehicles running down there are on alcohol.

We can't do that here, and we have the potential of producing this stuff here at far less than the cost of gasoline, and also the energy used to distill the alcohol can be used to generate—cogenerate if we have to.

There are so many things that we should be doing. I just don't think that we are doing them.

Thank you, Mr. Chairman.

Mr. **Valentine.** Thank you, Mr. Lewis.

The gentleman from California, Mr. Rohrabacher.

Mr. **Rohrabacher.** I was wondering what you thought about the potential of propane as a fuel.

Dr. **Berg.** Propane, methane, and any of the gaseous hydrocarbons have certain advantages, certain disadvantages. They burn cleaner than, say, gasoline, but at the same time some of the problems involved in fueling them and the quantity of fuel you have to carry on board and the size of the container to carry them is an extreme disadvantage.

However, there are certainly areas where they would be looked at in terms of their use on buses, particularly interurban type buses, where you don't have the need for storage racks and things like that where they would be held. I think that would be use.

Mr. **Rohrabacher.** I think propane basically could be used to fuel current engines, is that correct? We wouldn't have to actually build a whole new system of engines for our entire country; it is a way of fueling the engines without having to come up with a new engine?

Dr. **Berg.** That is true. All it takes is a little bit of change on the timing of the engine.

Mr. **Rohrabacher**. And it burns clean after that, is that correct, meaning it doesn't contribute to the air pollution?

So we have current engines—a fuel that we could use in current engines that would work without contributing to the air pollution problem, is that right?

Dr. **Berg**. We have reduced a lot of the pollution. We still have, obviously, some unburned hydrocarbons. You have NOX, but you will certainly eliminate a lot of the SOX and the actual reduction in the amount of carbon dioxide.

Mr. **Rohrabacher**. Would it then make sense to be focusing on a source of fuel that wouldn't require us to totally rebuild America's transportation system when we have so many automobiles and trucks, et cetera, with engines that could be serviced by propane rather than going to other exotic fuels and having to change the nature of the engines; for example, an electric engine?

Dr. **Berg**. There are certainly certain advantages to that, but again there would still be changes and the changes in the vehicle necessary in order to on-load it. In other words, it would take a different type of tank to carry it, and it would add more weight. Each one of these has advantages. Each has disadvantages.

The advantage with ethanol, say, at least you could use the tank that you have on board your truck, car, bus, whatever you have now, and it is a lot easier to replace, say, at the current filling station, take one of the gas pumps and dedicate it to certainly alcohol; whereas, you now have to have a liquid propane type tank that would have to sit there.

So there are tradeoffs on both sides.

Mr. **Rohrabacher**. When I drive down the freeways sometimes, I see these huge trucks. All of a sudden I will see this black stuff coming out of the smokestack into the air, and I can't help but believe that eventually that is ending up in someone's lungs.

Can propane propel a diesel type truck? Do we have a propane engine that could work like that?

Dr. **Berg**. You eliminate a lot of the particulate. Some of that particulate is actually the result of your lubricating oil being partially burned. About 40 percent of the particulate from diesel is that oil from the lubricating system.

So if you are running, say, a diesel type truck, you would still expect to have some of that particulate there. It would be far reduced from what it is now.

Mr. **Rohrabacher**. All right.

Mr. **Valentine**. I recognize the distinguished Ranking Republican on the full committee, Mr. Walker. We are glad to have you.

Mr. **Walker**. Thank you, Mr. Chairman.

If I add up the figures here, it looks to me as though we are going to spend about $15 million on essentially vehicle propulsion kinds of systems, whether they be alternative fuels, electric and hybrids, new propulsion systems of one kind or another. We have spent a great deal more than that in the past.

The bottom line, what are we trying to get out of this? Are we so unhappy with internal combustion that it is worth spending billions of dollars to find some alternative?

Dr. **Berg**. We are trying to do two things—one, improve the efficiency by which the fuel—and I say "the fuel"—is burned. Secondly, we are looking at alternative type fuels to burn in that engine.

Mr. **Walker**. To what end? Better environmental standards? Greater mileage? What is the bottom line we are trying to achieve?

Dr. **Berg**. That is exactly what we are trying to achieve. We are trying to achieve greater efficiency, less pollution.

Mr. **Walker**. Then why don't I see us doing anything with hydrogen?

Dr. **Berg**. Hydrogen is a secondary fuel, as I would call it. As I mentioned, we see that as a niche type market for certain applications.

Hydrogen requires a great deal of energy to break it apart from water. In addition to that is the problem of storage, not only storage but also containment.

One of the recent articles I saw this morning talked about Syracuse University now showing some great potential in using a carbonaceous material to absorb the hydrogen and then be able to release it with a change of temperature.

This is one of the biggest problems that hydrogen has. It liquefies at about minus 273 degrees. It is very cold and requires a great deal of insulation and a vacuum bottle, in essence, to contain it. It is extremely explosive, very difficult to handle.

Mr. **Walker**. No more so than gas is?

Dr. **Berg**. Far more so than gasoline.

Mr. **Walker**. I think there are people within the community who disagree with that and feel that the explosive power of hydrogen is not much different than the gasoline you now carry on board your motor vehicles.

Dr. **Berg**. I guess I would not want to be carrying a bottle—I would prefer carrying a bottle of gasoline in a can rather than, say, a bottle of hydrogen around if I was walking around the street.

Mr. **Walker**. On the other hand, that is the reason why it is more efficient, too. That is the reason why it is substantially more efficient. It burns more efficiently.

Dr. **Berg**. It does burn more efficiently, but by the time you wind up with the amount that you have as far as the volume is concerned, depending on how you are doing it, it could actually add greater volume than if you are going to have it under just a gaseous form. This has been one of the biggest problems, of course, is being able to have the same vehicle mileage and not increase the volume in order to contain that hydrogen on board.

Mr. **Walker**. I recognize there are problems out there. Otherwise, we probably would have gone to it a long time ago. But the fact is what we are trying to achieve is efficiency and environmental purity. Hydrogen is best from those two standpoints. As I indicated, it burns very efficiently and you end up with very little environmental degradation as a result of burning.

So to meet the goals that you just specified to me a moment ago, it seems to me that is something we ought to be doing, and it is not without problems. My concern is the fact that I don't see anywhere in your proposal that we are doing anything with the research that we are doing to work on those problems.

Dr. **Berg**. If I could just make one more comment about efficiency. Efficiency with the hydrogen burning is more efficient, but if I now consider the energy to form that hydrogen, it is not.

Mr. **Walker**. Again, isn't that something we ought to be looking at to figure out whether or not there is a regime by which we could make the hydrogen more effectively, too?

I mean, what I am saying is there is no research going on at all. The two things you say we want to achieve we could achieve with hydrogen, yet I don't see any money being spent for research for that, which if you look at the next century may well be the fuel that we have to go to, and we all of a sudden figure out that hydrocarbons aren't acceptable for any number of different reasons.

Dr. **Berg**. I would again come back to the fact that we have got a limited budget, and the priorities that we have are those that are established by peer review.

Hydrogen certainly has been talked about. Hydrogen could be made a priority. It is a priority, but it is a lower priority than what we have funds to fund.

Mr. **Walker**. How much money are you going to spend on hydrogen this year?

Dr. **Berg**. In the Department we are not spending any.

Mr. **Walker**. So in other words, it is a lower priority. It is a nonexistent priority as far as the Department is concerned?

Dr. **Berg**. It is a nonexistent priority in the budget we are submitting here. It certainly is on our priority list, but it is down in our priority list. If we had additional funds.

Mr. **Walker**. Thank you, Mr. Chairman.

Mr. **Valentine**. Thank you very much, gentlemen.

We will now recognize the second panel, if you gentlemen will come around.

That panel consists of Mr. Edwin Strain, Manager of Government Programs, Power Systems, Allied-Signal Aerospace Company, in Phoenix, Arizona; Mr. Harold E. Helms, Chief Engineer, Vehicular Turbines, Power Products Group, General Motors Corporation, Indianapolis, Indiana; and Mr. Noel Nightingale, Assistant General Manager, Stirling Engine Systems Division, Mechanical Technology, Inc., Latham, New York.

Welcome, gentlemen. Your prepared statements will appear in the record. You are welcome to proceed to summarize those or otherwise proceed any way you deem appropriate.

STATEMENT OF MR. EDWIN STRAIN, MANAGER, GOVERNMENT PROGRAMS, POWER SYSTEMS, ALLIED-SIGNAL AEROSPACE COMPANY, PHOENIX, ARIZONA; ACCOMPANIED BY MR. GARY BOYD, PROJECT MANAGER, ATTAP PROGRAM

Mr. **Strain**. Thank you, Mr. Chairman.

As indicated, I am Ed Strain. Thanks again for inviting us to the testimony today. I am Manager of Government Programs of the Garrett Auxiliary Power Division of Allied-Signal.

Mr. Gary Boyd will be assisting me today, who is our Project Manager on the ATTAP program.

Just to recount a little history, Garrett was the prime contractor for the advanced gas turbine program under contract to the Department of Energy and NASA. Allison also had a parallel contract. That program started in 1979 and was completed in mid-'87.

The ATTAP program, or advanced turbine technology applications project, was then initiated—

[Slide.]

—with Garrett again heading a planned five-year effort under DOE and NASA contract. Allison again had a parallel contract.

[Slide.]

In this testimony I wish to focus on why this country needs the ceramics technology being developed in the ATTAP program and requires continued U.S. Government support in 1990.

[Slide.]

The AGT program, which was completed in '87, as I said, was the major U.S. Government/industry sponsored program devoted to removing the ceramics from the research laboratories to a practical application of the automotive gas turbine engine.

Shown is the AGT-101, designed for 100 horsepower, 100,000 rpm maximum operating speed, with temperatures to 2500 degrees.

[Slide.]

The AGT program allowed an all-ceramic engine hot section to be designed from the sections. Shown on the chart are the ceramic parts, and as we had a chance to show you before the meeting started, at least the Chairman, we have the parts from the engine here on the table. All the parts—the major parts are shown here.

[Slide.]

DOE and ORNL initiated a generic ceramics program in 1984, called the Ceramic Technology for Advanced Heat Engines Program. The program was organized to assure that complementary efforts of the universities, industry, and the government would provide new, tougher, more reliable, and easier to produce ceramics or derivatives.

[Slide.]

As previously stated, the ATTAP was initiated in '87 and is a five-year program. Shown is the schedule of activities. Major program milestones show the program requirements for material assessment reviews, planned component and design fabrication, and significant tests.

The first of the contract milestones has been completed.

[Slide.]

Component fabrication activity has been initiated on five components selected as critical technology challenges during the AGT program. Three ceramic suppliers have been selected to develop the capability to fabricate the five components of the materials being developed, as shown on the chart.

As new materials evolve during the course of the program, either from the ORNL program or private industry, they will be introduced into the program.

Final verification of the ceramic methods will be manifested through component tests, intensive steady state and cyclic engine tests to 2500F and/or 100,000 rpm max speeds for periods up to 300 hours.

[Slide.]

What if ATTAP is not continued?

We think ceramics development in this country would slow dramatically.

Foreign competition could bypass the U.S. industry and offer ceramics for many applications. As a result of the AGT and ATTAP programs, the U.S. currently leads in the ceramic gas turbine development.

[Slide.]

Ceramics development is a national goal in Japan. The Japanese government is sponsoring a gas turbine program similar to our program. It was started in 1988. Two programs, one in automotive and one in industrial, and you will note that three leading Japanese companies are involved in each of the two programs.

These teams are working diligently with a lot of funding to develop ceramic gas turbines in Japan.

[Slide.]

In addition, Nissan has sold over 150,000 vehicles employing ceramic turbochargers, although Gene tells me that the number—and he just returned—that the number is much higher than that.

[Slide.]

In addition, Europe has initiated a new ceramic automotive gas turbine program, called the AGATA program, or Advanced Gas Turbine for Automobiles. You will note the five major automotive companies involved in this government/industry sponsored program.

[Slide.]

We recommend the following.

Continue funding the DOE/ORNL ceramic technology project in FY '90 in accordance with the program plan developed by DOE with inputs from industry.

We think we should continue the ATTAP program in '90 with both contractors. We recommend $6 million funding for each contractor and that an additional 1 to 1.5 million be provided to NASA for project management. This would total $13.5 million.

The contractors will be providing an additional 20 percent cost sharing, as stated earlier.

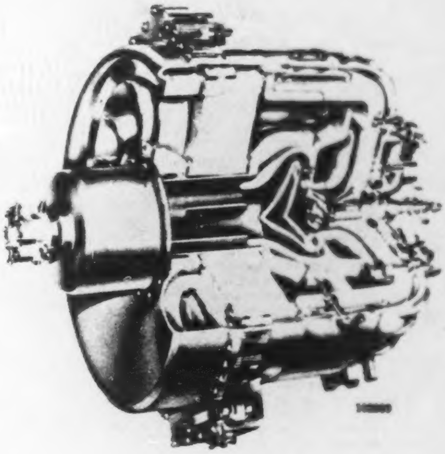
Thank you.

[The prepared statement of Mr. Strain follows.]

Testimony
Before The
Committee on Science and Technology
Subcommittee on Transportation,
Aviation and Materials
United States House of Representatives

PROGRESS REPORT
GARRETT
ADVANCED TURBINE TECHNOLOGY APPLICATIONS PROJECT

ATTAP



8 MARCH 1989

EDWIN STRAIN
Manager, Government Programs
Garrett Auxiliary Power Division

Allied-Signal Aerospace Company
Garrett Auxiliary Power Division
AlliedSignal

E. E. STRAIN

Manager, Government Programs,
Garrett Auxiliary Power Division

Education

B.S., Aeronautical Engineering, Northrop Institute of Technology, 1962

Graduate Study, Aeronautical Engineering, UCLA

Work History

1968 to date: Garrett Auxiliary Power Division

- Manager, Government Programs
- Manager, Military Programs
- Program Manager
- Program Administration

1965 to 1968: Rocketdyne

- Project Development Manager

1964 to 1965: Aerojet

- Manager of Small Engines Advanced Technology

1957 to 1964: Rocketdyne

- Project Engineer
- Field Engineering Manager
- Development Engineer

Responsibility/Experience

Mr. Strain has served as manager of numerous open- and closed-cycle gas turbine programs at GAPD. A majority of the programs were Government sponsored. Some of the programs and sponsoring organizations are listed below:

- Gaseous Diffusion Compressors/Valves-DOE/Union Carbide/Goodyear
- Advanced Gas Turbine - DOE/NASA
- Brayton Isotope Power System - DOE
- Brayton Conversions Module - DOE/JPL/NASA
- Closed Cycle Gas Turbine Heater - DOE
- Advanced Cogeneration Systems - DOE/NASA
- AH-64A Auxiliary Power Unit - Hughes/U.S. Army
- Enhanced Oil Recovery Cogeneration System - GWF Power Systems
- Alternate Fuels Evaluation - U.S. Air Force
- Gaseous Diffusion Compressors - Bechtel Corp.
- Improved Gas Turbine - Ford Motor Co.
- Ceramic Technology Readiness - DOE
- DIVAD Primary Power Unit - Ford/U.S. Army
- B-1 Secondary Power - Rockwell/USAF
- F-18 APU - Northrop/U.S. Navy
- F-15 Secondary Power - McDonnell Douglas/USAF
- C-2 APU - Grumman/U.S. Navy
- S-3A APU - U.S. Navy
- Aviation Ground Power Unit - Development Sciences/U.S. Army
- Large Aircraft Start System - Libby Corp./USAF
- Advanced Turbine Technology Applications Project

Additional experience at GAPD has involved project administration tasks associated with open- and closed-cycle gas turbine programs.

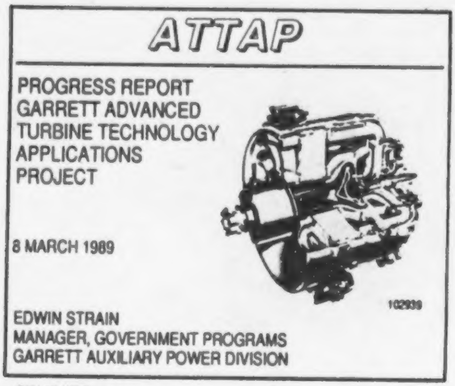
At Rocketdyne and Aerojet, Mr. Strain performed a variety of engineering and management functions related to the development and production of rocket engines. Significant programs in which he was involved were the Gemini, Apollo, Atlas, Thor, and Saturn rocket engine and system development and production.

Professional Affiliations

- American Helicopter Society
- AIAA

Mr. Chairman and Members of the Committee:

My name is Edwin Strain. I am Manager of Government Progams, Garrett Auxiliary Power Division, the Allied-Signal Aerospace Company, a unit of Allied-Signal, Inc. (Figure 1).



ATTAP

PROGRESS REPORT
GARRETT ADVANCED
TURBINE TECHNOLOGY
APPLICATIONS
PROJECT

8 MARCH 1989

102939

EDWIN STRAIN
MANAGER, GOVERNMENT PROGRAMS
GARRETT AUXILIARY POWER DIVISION

GC9-47-1(BK)

Figure 1. Testimony Before the Committee.

Garrett was the prime contractor for the Advanced Gas Turbine (AGT101) Program under contract to the Department of Energy and NASA. That program started in 1979 and concluded in mid-1987. The Advanced Turbine Technology Applications Project (ATTAP) was initiated in mid-1987 with Garrett again heading a planned five-year effort under DOE/NASA contract.

The AGT101 team developed high-risk, long-range, proof of concept technology for advanced gas turbines for future automotive and other power plant uses. A major emphasis of the program was the development of ceramic component technology for gas turbine engines.

The ATTAP program expands on the AGT101 effort and the companion DOE Ceramic Technology for Advanced Heat Engines Project, (CTAHE), to continue to advance U.S. ceramic technology through the development of processes to fabricate and test components from improved (next generation) ceramic materials.

In this testimony, we wish to focus on why this country needs the ceramics technology being developed in the ATTAP program (Figure 2) and requires continued U.S. Government support in 1990.

U.S. NEEDS CERAMIC TECHNOLOGY
THAT IS BEING PROVIDED BY THE
ATTAP PROGRAM

G89-47-2(BK)

Figure 2. Today's Focus.

I. WHAT IS CERAMICS?

- o Ceramics is a science related to nonmetallic and inorganic materials.
- o Silicon, nitrogen, and carbon are elemental constituents (i.e., sand).

II. WHY IS CERAMICS IMPORTANT?

- o Elemental constituents are readily available in the U.S. in an inexhaustible supply.
- o The need for strategic materials[1] is reduced (many heat engines, including gas turbines, employ strategic materials).

---

[1] "A strategic material is one for which the quantity required for essential civilian military uses exceeds the reasonably secure domestic and foreign supplies, and for which acceptable substitutes are not available within a reasonable period of time." Office of Technology Assessment, Strategic Materials: Technology to Reduce U.S. Import Vulnerability (January 1985), p. 13.

- Reduced reliance on foreign sources[2], improving position of National Security.
- There are not enough strategic materials in the world for automotive gas turbine production.
- Cost of strategic materials for an automotive gas turbine is prohibitive.

o Ceramics[3] offers the automotive gas turbine (Figure 3):

- MATERIALS AVAILABLE IN U.S. IN INEXHAUSTIBLE SUPPLY
- NEED FOR STRATEGIC MATERIALS REDUCED
- CERAMICS FOR AUTOMOTIVE GAS TURBINE ARE ESSENTIAL
  - COST
  - HIGHER EFFICIENCY — BETTER FUEL CONSUMPTION
  - ADEQUATE RAW MATERIAL FOR MASS PRODUCTION

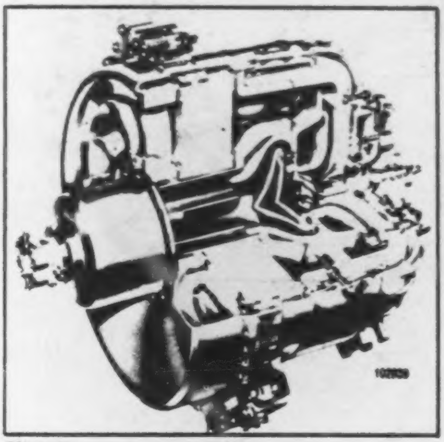
GC9-47-3(BK)

Figure 3. The Importance of Ceramics.

- Capability to operate at higher temperatures without cooling, thus providing higher efficiency
- Better fuel economy
- Substantially lower cost potential
- Adequate raw material for mass production
- Lower friction (tribology)
- Lower weight
- Lower inertia of rotating parts (less energy)

III. WHAT DID THE AGT PROGRAM ACCOMPLISH?

o The AGT program completed in 1987 was the major U.S. Government/industry-sponsored program devoted to moving the focus of ceramics from the research laboratories to a practical application -- an automotive gas turbine engine (Figure 4). Shown is the AGT101 designed for 100 horsepower, 100,000 rpm maximum operating speed and temperatures to 2500F.



GC9-47-4(BK)

Figure 4. AGT101 Power Section.

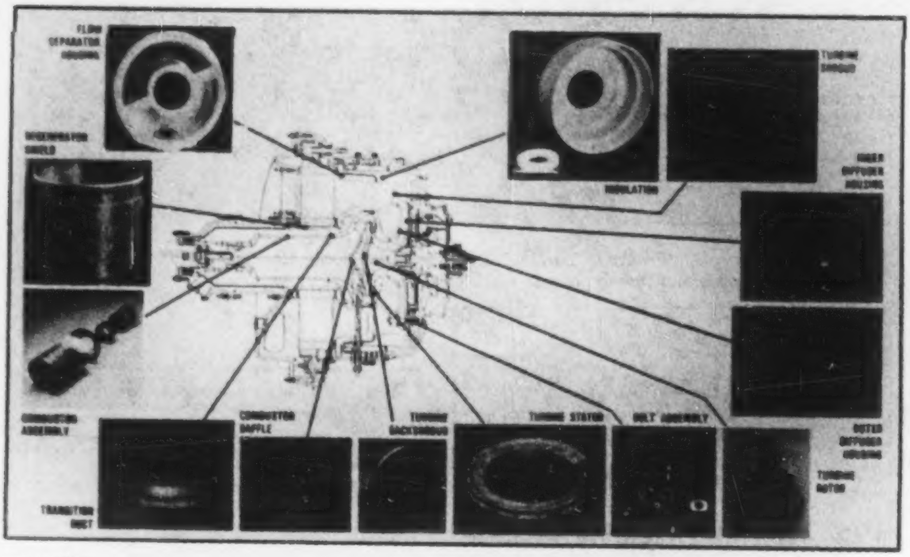
o The AGT program was the only one in the U.S. that allowed an all-ceramic engine hot section to be designed from inception (Figure 5).

o The program allowed ceramics expertise from the automotive, gas turbine, ceramics industries, and the government to develop ceramics technology and integrate this technology into the gas turbine operating environment via test rigs and engine test beds -- the only practical approach to ceramics technology development.

---

[2] "Three nations, South Africa, Zaire, and the U.S.S.R., account for over half of the world's production of chromium, cobalt, manganese, and platinum group metals." Ibid., p.7.

[3] "Ceramics, composites, and unconventional metallic materials have properties that suggest they might serve as substitutes for conventional materials that require strategic metals." Ibid., p. 52.


FLOW SEPARATOR HOUSING
REGENERATOR SHIELD
COMBUSTOR ASSEMBLY
TRANSITION DUCT
COMBUSTOR BAFFLE
TURBINE BACKSHROUD
TURBINE STATOR
BOLT ASSEMBLY
INSULATION
TURBINE SHROUD
INNER DIFFUSER HOUSING
OUTER DIFFUSER HOUSING
TURBINE ROTOR

GC9-47-5(BK)

93741

Figure 5. AGT101 Ceramic Components.

- o The program allowed the AGT team to advance this long-range, high-risk technology, which no individual company could afford.
- o AGT testing accomplishments
  - 165 components at 25-percent greater stress than engine operation
  - Multifuel demonstration
  - Structural ceramic components tested over 40 hours at 2500F (Figure 6)
  - Ceramic components tested in engine test beds for 250 hours (Figure 7)
  - 100-hour endurance test at 2500F on one set of ceramic components
  - All-ceramic engine successfully tested at 2500F for 85 continuous hours
  - Ceramic turbine successfully tested to 100,000 rpm in an engine

IV. WHERE DO ATTAP AND CTAHE PROGRAMS TAKE US?

- o DOE-ORNL initiated a generic ceramics program in 1984 called the Ceramic Technology for Advanced Heat Engines (CTAHE) Project. This program is organized to assure that complementary efforts of universities, industry, and the Government provide new, tougher, more reliable, and easier-to-produce ceramics or derivatives (Figure 8).
- o As previously discussed, the AGT101 program provided significant accomplishments in the development of first-generation ce-

- 185 CERAMIC STRUCTURES PASS PROOF TEST
  - 1.25X NORMAL START TRANSIENT PEAK STRESS
  - NORMAL START TRANSIENT AMBIENT 2200F IN 5 SECONDS
- *CERAMIC COMBUSTOR OPERATIONS* ON JP-4, DF-2, GASOHOL
- OVER 40 HOURS ACCUMULATED AT 2500F
  - SASC
  - SSN

GB9-47-6(BK)

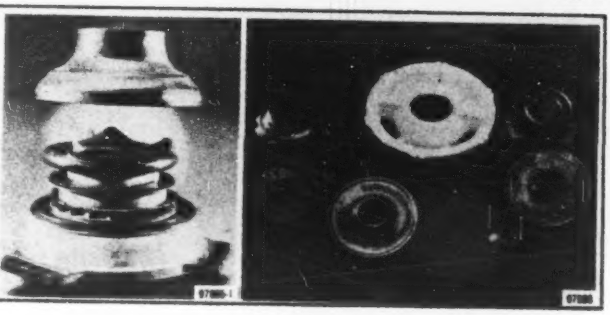
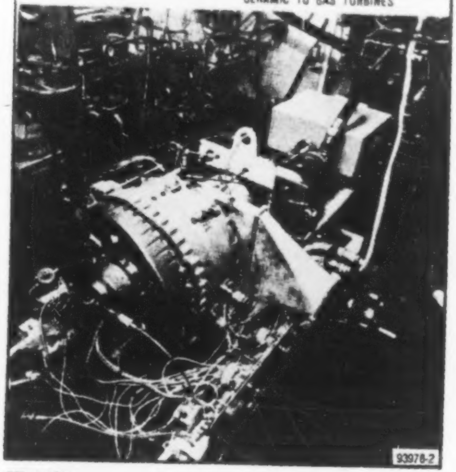


Figure 6. Progress Has Been Demonstrated in the Ceramic Component Designs and Development.

- CERAMIC STRUCTURES SUCCESSFULLY COMPLETE 100-HOUR ENDURANCE AT 2100F
  - CERAMIC TURBINE SUCCESSFULLY OPERATED TO 100,000 RPM 2300 FT/SEC TURBINE TIP SPEED
    - ONE ALL-CERAMIC ENGINE ACCUMULATED 85 HOURS AT 2200F
      - AGT PROGRAM DEMONSTRATED FEASIBILITY OF APPLYING CERAMIC TO GAS TURBINES



GB9-47-7(BK)

Figure 7. Over 250 Hours Accumulated on AGT101 Engines With Ceramic Components.

- DOE-ORNL INITIATED CERAMIC TECHNOLOGY FOR ADVANCED HEAT ENGINE (CTAHE) PROGRAM IN 1984
- DEVELOPING TECHNOLOGY BASE IN STRUCTURAL CERAMICS, CERAMIC COMPOSITES AND COATINGS CAPABLE OF PROVIDING RELIABLE AND COST EFFECTIVE COMPONENTS

GC9-47-8(BK)

Figure 8. DOE-ORNL Sponsoring Technology Research for Next Generation Ceramics.

ramics; however, the ceramics need considerably more development before they can be used commercially. We know that questions relating to second-generation materials, reliability, supply infra-structure, the demands for high quality components produced in cost effective quantities, and others remain unanswered.

o The value of using realistic operating hardware when attempting to answer these questions is beyond doubt. The AGT and ATTAP programs provide already-paid-for test rigs and engine test beds for developing and evaluating the next generation of ceramics, once the parts are fabricated.

o DOE planned the ATTAP program (Figure 9) to continue the ceramic techology effort

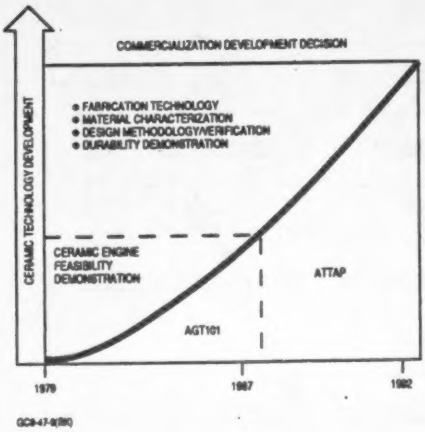


Figure 9. ATTAP Will Continue U.S. Ceramic Technology Development.

inititated in the AGT and CTAHE programs such that the United States will not lag behind world competition. The objective of the ATTAP is to continue to advance U.S. ceramics technology through the development of processes to fabricate and test components from the improved (next generation) ceramic materials, refine and enlarge ceramic properties experimental data base, expand analytical tools needed to support the ceramic industry, evaluate the reliability and durability of the next generation of high temperature ceramics and publish a ceramic design manual (Figure 10).

- The ATTAP was initiated in 1987 and is a 5-year program. Figure 11 shows a schedule of planned activities. Major program milestones (placed on the top of the schedule) show the program requirements for materials assessement reviews, turbine stage component design and fabrication, and significant engine tests. The first two contract milestones have been completed.

U.S. CERAMIC SUPPLIERS

- MATERIALS ASSESSMENT
- CANDIDATE MATERIALS CHARACTERIZATION
- COMPONENT FABRICATION PROCESS DEVELOPMENT
- IN-PROCESS AND FINAL COMPONENT NDE TECHNIQUE DEVELOPMENT
- DESIGN METHODS DEVELOPMENT AND VERIFICATION ORNL LIFE PREDICTION PROGRAM
- ENGINE TEST BED PERFORMANCE AND COMPONENT DURABILITY
- PUBLICATION OF CERAMIC DESIGN MANUAL

G88-47-10(BK)

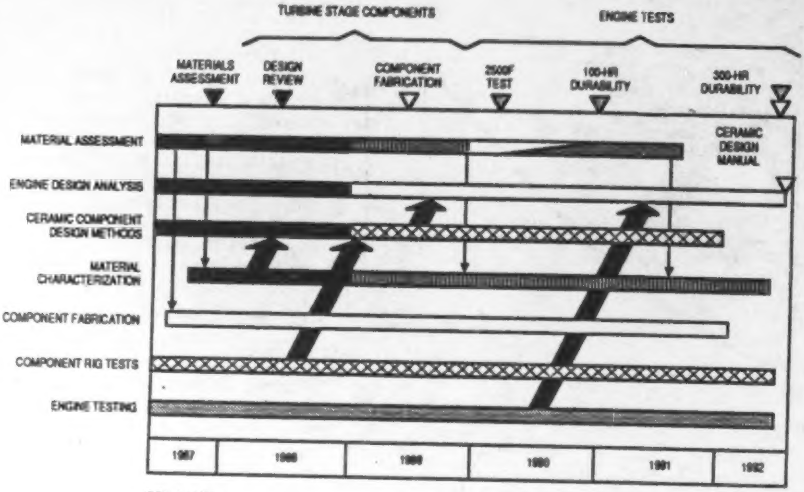
Figure 10. ATTAP Objectives Address the AGT101 Technology Challenges.

- The schedule shows the flow of information from materials assessment to materials characterization and on to component fabrication. Component material characterization is compared with laboratory test specimens to assess the level of process maturity and supplements data required for component probabilistic life prediction methods development and verification.

- Component fabrication activity has been initiated on five components selected as critical technology challenges during the AGT101 program. These components, depicted in Figure 12, require further process development to demonstrate net shape fabrication capability, reliability and yield.

- Three ceramic suppliers have been selected to develop the capability to fabricate the five components from materials being developed by them.

- As new materials evolve, either from the CTAHE program or by private industry, they will be introduced into the program. The materials will be subjected to the same screening tests performed on the current materials prior to their acceptance into the program. In addition, the suppliers must have production capability before they are acceptable.



GC9-47-11(BK)

Figure 11. Technology Challenges Set ATTAP Milestones.

- Final verification of the ceramic life prediction methods will be manifested through component tests, intensive steady state and cyclic engine tests to 2500F and/or 100,000 rpm for periods to 300 hours.

- The ATTAP culminates in publication of a Ceramics Design Manual, which will provide verified design methods, test procedures, nondestructive evaluation techniques and material specifications for use by U.S. industry.

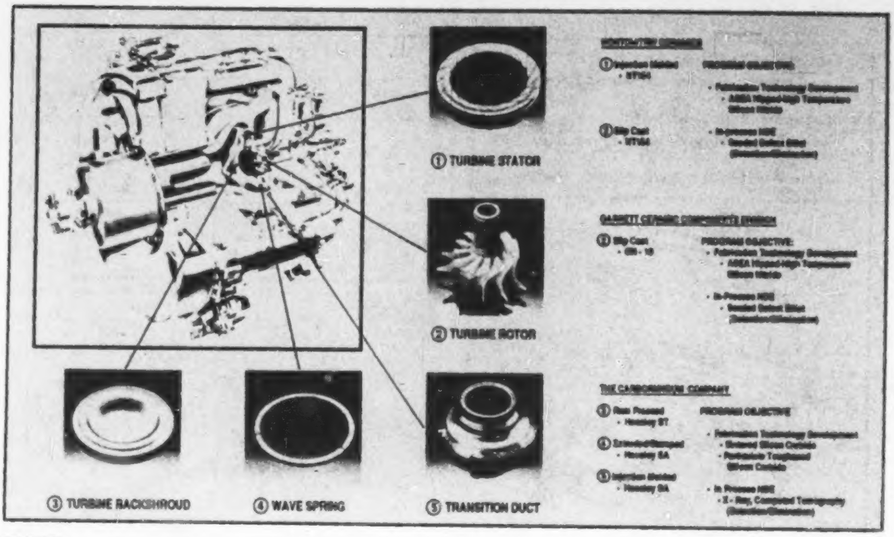
- ATTAP progress to date is summarized in Figure 13.

V. WHAT IF ATTAP IS NOT CONTINUED (Figure 14)?

- The technology base developed by the ATTAP program is directly responsible for a large number of ceramic spinoff efforts and has served as a catalyst for industry to greatly increase their company-sponsored R&D.

- If ATTAP is not continued ceramics development in this country could slow dramatically. Since the technology is still considered long range and high risk, U.S. industry may limit resources to bring ceramics to production status. The ATTAP program concentrates on high-temperature, high-stress environmental challenges not addressed in any other ceramic technology program.

- Foreign competition will bypass U.S. industry and offer ceramics for many applications before our industry does. As a result of the AGT and ATTAP programs, the U.S. currently leads in ceramic gas


① TURBINE STATOR
② TURBINE ROTOR
③ TURBINE BACKSHROUD
④ WAVE SPRING
⑤ TRANSITION DUCT
GARRETT CERAMIC COMPONENTS DIVISION
PROGRAM OBJECTIVE:
THE CARBORUNDUM COMPANY
PROGRAM OBJECTIVE

GC9-47-12(BK)

Figure 12. Initial Ceramic Components Selected for Process Development

turbine development. Ceramics development is a national goal in Japan. New ceramic gas turbine programs, similar to the U.S. programs, were started in 1988. Note that three leading Japanese automotive companies are teaming on the ceramic gas turbine program for automobiles. They will undoubtedly spend far more than the Government funding (Figure 15).

o In addition, Nissan has sold over 150,000 automobiles employing ceramic turbocharger turbine wheels (Figure 16). As a result, Japan leads the world in the initial mass production of ceramic turbine wheels. This technology and production base could allow Japan to be first in introducing ceramic gas turbines into the automotive market if the ATTAP programs is not continued.

o Europe too has initiated a new ceramic automotive gas turbine program called AGATA (Advanced Gas Turbine for Automobiles). As shown in Figure 17, five major automotive companies are involved in the Government/Industry sponsored program.

o The gas turbine offers the best option for a polution-free automobile engine. Required emission levels can be met without aftertreatment devices while using standard or alternate fuels.

o The world oil supply is limited. In the event of a return of the fuel crisis, U.S. industry will be ill-prepared without alternative fuel efficient and multi-fuel-burning power plants.

- INITIAL TWO PROGRAM MILESTONES COMPLETED
- THREE SUPPLIERS QUALIFIED AND PROGRESSING WITH CERAMIC COMPONENT FABRICATION
- MATERIAL CHARACTERIZATION IS PROCEEDING
- A TWO-YEAR IMPACT STUDY WAS INITIATED TO SUPPORT CERAMIC DESIGN METHODS
- IMPROVEMENTS UNDERWAY TO UPGRADE THE ENGINE TEST BED FOR 2500F OPERATION

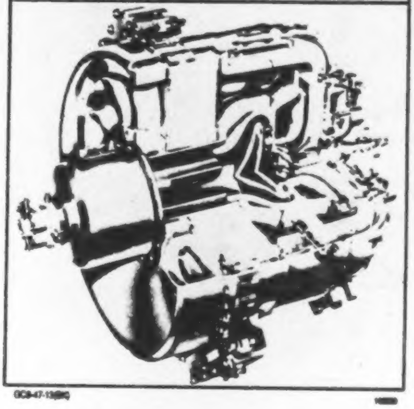


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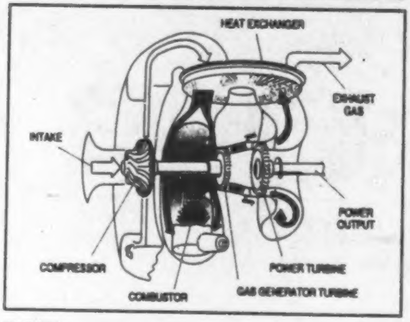
Figure 13. ATTAP Moving Forward to Meet Program Goals.

- U.S. CERAMICS DEVELOPMENT WILL SLOW
- FOREIGN COMPETITION WILL BYPASS U.S. CERAMICS TECHNOLOGY
- RETURN OF FUEL CRISIS WOULD FIND U.S. AUTO INDUSTRY WITHOUT ALTERNATIVE FUEL-EFFICIENT AND MULTI-FUEL BURNING POWER PLANTS

G89-47-14(BX)

Figure 14. Lack of Future Development Would Prove Detrimental.

	AUTOMOTIVE CGT (100kW)	INDUSTRIAL CGT (300 kW)
STARTING DATE	JULY 1988	OCTOBER 1988
PERIOD	9 YRS (WITH FIRST 2 YRS OF PRELIMINARY STUDY)	8 YEARS
BUDGET	15 BILLION YEN ($115 MILLION)	16 BILLION YEN ($125 MILLION)
INDUSTRIAL PARTICIPANTS	TOYOTA NISSAN MITSUBISHI	IHI GROUP KHI GROUP YDE GROUP



GC9-47-15(BX)

Figure 15. Japanese Initiating Ceramic Gas Turbine Programs.

VI. WHAT DO WE RECOMMEND (Figure 16)?

- o Continue funding the DOE/ORNL ceramic technology for advanced heat engines Project in FY 1990 in accordance with the program plan developed by DOE with inputs from industry.
- o Continue the ATTAP program in FY1990 to develop and evaluate the next generation of ceramics.
- o Keep both ATTAP contractors involved.

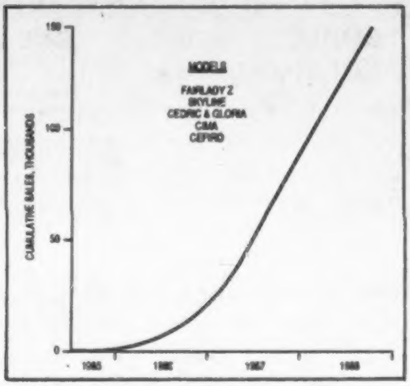


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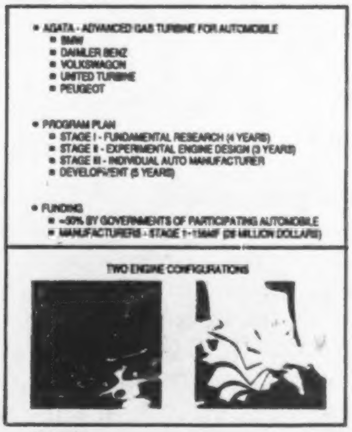
Figure 16. Nissan Has Sold 150,000 Vehicles With Ceramic Turbochargers.

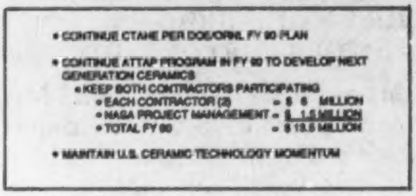


- AGATA - ADVANCED GAS TURBINE FOR AUTOMOBILE
  - BMW
  - DAIMLER BENZ
  - VOLKSWAGON
  - UNITED TURBINE
  - PEUGEOT
- PROGRAM PLAN
  - STAGE I - FUNDAMENTAL RESEARCH (4 YEARS)
  - STAGE II - EXPERIMENTAL ENGINE DESIGN (3 YEARS)
  - STAGE III - INDIVIDUAL AUTO MANUFACTURER
  - DEVELOPMENT (5 YEARS)
- FUNDING
  - ~30% BY GOVERNMENTS OF PARTICIPATING AUTOMOBILE
  - MANUFACTURERS - STAGE 1 - 136MF (26 MILLION DOLLARS)

TWO ENGINE CONFIGURATIONS

GC9-47-17(BK)

Figure 17. European Consortium Initiates AGATA Program.



- CONTINUE CTAHE PER DOE/ORNL FY 90 PLAN
- CONTINUE ATTAP PROGRAM IN FY 90 TO DEVELOP NEXT GENERATION CERAMICS
  - KEEP BOTH CONTRACTORS PARTICIPATING
    - EACH CONTRACTOR (2) = $ 6 MILLION
    - NASA PROJECT MANAGEMENT = $ 1.5 MILLION
    - TOTAL FY 90 = $ 13.5 MILLION
- MAINTAIN U.S. CERAMIC TECHNOLOGY MOMENTUM

GC9-47-18(BK)

Figure 18. Recommendations.

- Fund at least $6 million per contractor in FY1990
- Provide funding for NASA Project Management in FY1990 which is approximately $1-1.5 million
- Estimated total ATTAP funding for FY1990-FY1992

Contractors (2)	= $ 30 million*
NASA Project Management	= $ 4 million
Total	= $ 34 million

*Does not include contractor's cost sharing of approximately $6 million.

o Maintain U.S. ceramic technology momentum.

Mr. **Valentine**. Thank you, sir.
Mr. Helms.

STATEMENT OF MR. HAROLD E. HELMS, CHIEF ENGINEER, VEHICULAR TURBINES, POWER PRODUCTS GROUP, GENERAL MOTORS CORPORATION, INDIANAPOLIS, INDIANA

Mr. **Helms**. Thank you, Mr. Chairman, for the opportunity to speak to you today. I will depart from the submitted testimony and speak extemporaneously to about half of that at this point.

It has been our pleasure at General Motors to be part of the DOE ceramic gas turbine activities.

[Slide.]

We at General Motors have provided two sets of work groups, the Allison Gas Turbine Division and now the Advanced Engineering Staff at the General Motors Technical Center, to address the subject of ceramic gas turbines. Even though we still consider this a high risk, high payoff type program, we are getting more and more serious as we move down the track.

[Slide.]

Right now I would have to observe that the Department and the U.S. Government stands to get significant applause. As far as I am concerned, I believe that the overall DOE ceramics team that has been put into place is leading the world in the ceramics technology today.

We at Allison consider ourselves consider ourselves to be one of six members of that DOE team that has been put into place. Garrett and ourselves share similar programs. We believe that is constructive because there is natural competition, number one, and there are different approaches to the ceramics technology area.

We feel very closely knit with NASA and the Oak Ridge National Laboratory activities, and naturally both Garrett and Allison are contracting with many ceramic components suppliers in this country to build the expertise that we think is required in the coming years, and we all interface with the university community as we move forward with this new technology in the area of ceramics.

[Slide.]

I flash on the board here the fact that we have just recently received a program out of the Oak Ridge National Laboratories which addresses life prediction capabilities for these new materials.

Believe me, we are still in the steep part of the learning curve for these ceramic materials, especially with the composite ceramic materials as compared to the monolithic types.

[Slide.]

We are very appreciative of being a part of that program.

Now, I show here a similar chart to what Mr. Strain showed for the ATTAP program. I would just call your attention to the fourth line down on that chart, which says "Design with ceramics."

We feel that we are learning much in the area of making and processing of ceramics, but at the same time we are rapidly learning how to design with ceramics, exclusive of what the properties of ceramic materials are.

[Slide.]

To make the point relative to the companies that General Motors is working with under the ATTAP program, we are working with this series of companies, the Carborundum Company, the GTE Laboratories, the Garrett Ceramics Company, Corning Glass Company, Ceramics Process Systems Group, Drexel University, General Electric in Schenectady, and Manville, located in Denver.

More than 50 percent of our budgeted ATTAP funds are being devoted to the ceramics activity, which certainly places the emphasis in our program on ceramics.

[Slide.]

I have in front of me three turbine rotors. I don't know if you can see those or not. Perhaps you might like to look at them after the testimony. But those three turbine rotors all do the same job.

This one has 38 blades. This one has 20 blades. And this one has 15 blades. There are different aerodynamics involved, but as we address the particular engine that we are using in our program—

[Slide.]

—which is this one, the AGT-5 automotive gas turbine, by changing the design of the aerodynamics we can begin to accommodate the special properties that the ceramics offer as compared to metals that we have used in the past in the gas turbine engines.

We feel this design iteration with the basic ceramic properties is a key part of the technology that we are gradually unfolding in this very complex ceramics technology area.

[Slide.]

That engine that I showed, the AGT-5, has been run this past year at the General Motors Technical Center, and on that particular engine we have accumulated 391 total hours, and the high time rotor that we have run, which is this heavy rotor with the 15 blades, has withstood all of the foreign object damage that we have been able to throw at that rotor to date.

Since it does represent a compromise in aerodynamic efficiency, we are backing off to this rotor, which gains back some of the aerodynamic efficiency. But I hope this example illustrates to you some of the complexity that it takes to apply this new family of materials that is being born here within our country.

I think we are leaders at this time in this technology overall.

[Slide.]

Now, I show this car just to illustrate the fact that General Motors has invested in automobiles that can begin to understand and to put in place the technology to use gas turbine engines in future automotive products.

That is the Chevrolet Express that we have shown here in the last couple of years. We could have brought it this year. I am glad we didn't because of the weather that we had today.

But again the ceramics technology effort we feel is extremely constructive.

That is the last of my slides, but I would like to make a couple of other comments.

This past week I was in Japan. I was an invited guest of the Japanese government. I did talk to all of the contractors that are involved in the Japanese ceramic gas turbine program. Their funding level for those two size engines is roughly $27 million per year on the average through the nine-year program that they have in place.

I observed that relative to the gas turbine system that I believe we lead the Japanese in technology today. I believe they are posturing themselves to overtake us and to surpass us if we relax and back off on the funding from the government and from industry that is already going into our program.

We are going to lose our competitive lead, and with the emphasis we have on competitiveness, I hope instead we maintain, if not increase, the support for this kind of program.

One of the best programs I have seen out of the U.S. Government in the past 10 years, it is obviously helping to supply the basic technology that is really going to help American industry, and to back off on it in my book would be very wrong to do at this time.

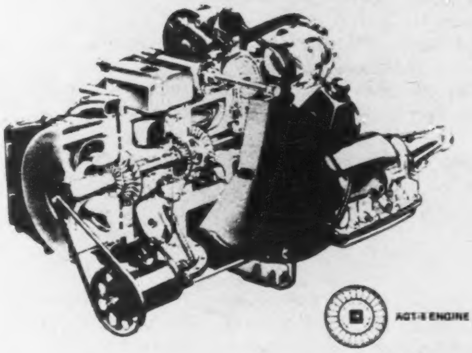
Thank you for my opportunity to present this to you. If you have questions, I will try to answer them, sir.

[The prepared statement of Mr. Helms follows.]

Testimony to the
House Subcommittee on Transportation,
Aviation and Materials
of the
Committee on Science, Space, and Technology
U.S. House of Representatives

8 March 1989

ATTAP



Department of Energy Advanced Turbine Technology Applications Project

Harold E. Helms, Chief Engineer

Allison Gas Turbine Division
General Motors Defense Operations Group
General Motors Corporation

HAROLD E. HELMS
Chief Engineer--Vehicular Turbines

Education
B.S. Engineering Mechanics, Purdue University, 1948
M.S. Engineering Mechanics, Purdue University, 1950

Work History

1952 to Date: Allison Gas Turbine Division
General Motors Corporation
P.O. Box 420
Indianapolis, Indiana 46206

- Chief Engineer, Advanced Vehicular Engines
- Chief--Regenerator Systems
- Program Manager--NASA QCSEE Program
- Chief--Analytical Mechanics
- Section Head--Stress, Heat Transfer, Vibrations, Weights, and Computers
- Supervisor--Rocket Nozzles and Cases
- Deputy Leader--Allison/Rolls Royce Joint Project
- Senior Project Engineer--T40 Engines, T56 Engines

1950 to 1952: Engineer, Argonne National Laboratory, Lemont, Illinois
1946 to 1950: Instructor--Advanced Mechanics, Purdue University, West Lafayette, Indiana

Responsibility/Experience

Mr. Helms is responsible for advanced technology vehicular engines at Allison. This responsibility includes the ATTAP Program--DOE/NASA contract and Fuel Cell Advanced Technology Engines, and Coal Burning Turbines. The ATTAP Program was planned and is directed under Mr. Helms' leadership. Ceramic materials technology is the major thrust of this program and he is a recognized leader in the application of ceramic components in heat engines.

Analytical Mechanics, including stress analysis, heat transfer, vibrations, weights, and computer analysis, was directed by Mr. Helms. Turbine cooling, including convection, film, and transpiration cooling methods, was implemented and developed under Mr. Helms. Lamilloy, an Allison invention, was conceived and developed under his direction.

Mr. Helms' prior experience includes work on rocket motor cases and nozzles and turboprop, turbofan, turboshaft, and turbojet engines at Allison. Mr. Helms also worked on the Atomic Energy Commission reactor project for the Nautilus submarine.

INTRODUCTORY REMARKS

Thank you, Mr. Chairman, for this opportunity to present a status report on the Allison Gas Turbine Division of General Motors "Advanced Turbine Technology Applications Project" (ATTAP). The Department of Energy (DOE) has provided funding and the National Aeronautics and Space Administration (NASA) has administered this work with Allison. I am Gene Helms, Chief of Vehicular Turbines and program manager for the Allison ATTAP program.

CERAMIC GAS TURBINES

The basic "ceramic gas turbine" (CGT) concept is derived from a long-term requirement to achieve engineering materials with much higher operating temperature capabilities than metals used in the hot flow path in past and current gas turbine engines. The current temperature limit for metals is approximately 1093°C (2000°F), and that is for very expensive superalloy materials. The initial goal for structural ceramic materials in gas turbines has been at 1370°C (2500°F). This improvement beyond 1093°C can nearly double power for a given flow size gas turbine. A long-term goal for structural ceramic materials in gas turbines is 1650°C (3000°F) which permits nearly stoichiometric gas temperature in the turbine. This improvement beyond 1093°C can nearly triple power for a given flow size gas turbine. As the gas turbine temperature increases, power increases and thermal efficiency improves. At the long term goal (1650°C), the thermal efficiency is over 50%. This compares to a basic automotive spark ignition (SI) engine thermal efficiency in the range of 22% to 27% and to a gas turbine efficiency of approximately 42% at the initial goal level of 1370°C. These numbers translate to an automotive fuel economy of 23-28 miles per gallon with a spark ignition engine, 38-45 miles per gallon with an initial goal ceramic gas turbine engine, and to 52-60 miles per gallon with a long-term goal ceramic gas turbine engine. It is observed that this fuel economy payoff is far greater than any future spark ignition engine may offer. Figure 1 shows U.S. petroleum usage in 1987 and the highway vehicle predominance of fuel consumption. The importance of thermal efficiency of vehicle powerplants is evident and clearly justifies development of improved heat engines.

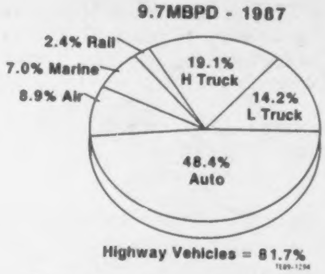


Figure 1. Petroleum use by mode–9.7 MBPD (1987).

Multifuel capability is a very desirable characteristic in heat engines. The gas turbine successfully operates on fuels which vary from pure hydrogen, to methane/propane, to alcohol fuels (ethanol/methanol), to gasoline and diesel fuels and on clean, micronized powdered coal. The gas turbine engine is the only practical automotive heat engine with this fuel flexibility.

Low emissions have been demonstrated with gas turbine engines. The continuous combustion in the gas turbine presents the opportunity of fuel/air ratio control over an operating regime that is much better than the off/on combustion of spark ignition and compression ignition engines. The type of gas turbine combustor affects the level of pollutants also. For example, the cleanest observed combustion in a gas turbine has been achieved with the prevaporization, pre-mix type combustion system. Staged combustion has also achieved good results and diffusion flame combustion is the least satisfactory from a pollution standpoint. The better combustors offer the capability of meeting requirements presented in Federal Emission Standards.

Thus, the ceramic gas turbine offers three key advantages over metal gas turbines and other types of heat engines. These significant advantages are the following:

- improved fuel economy
- multifuel capability
- low emissions

Marketplace discriminators are of prime importance in product development. For the automotive marketplace, the order of importance is as follows:

- cost
- reliability
- performance

The volumes of automotive engines are in the hundreds of thousands per year and the average cost is on the order of $5.00/lb. of engine weight. There is no experience base for gas turbines in the world at these volumes and costs.

The current worldwide gas turbine production for all applications is approximately 13,500 engines per year. The cost for aircraft gas turbines is of the order of $500.00/lb, approximately 100 times the required cost for automotive gas turbines. This reflects the following marketplace discriminator priority order for aircraft:

- performance
- reliability
- cost

Ceramic materials development is a key technology in helping to bring cost under control in the automotive gas turbine scenario. It is readily observed that a new generation of ceramic gas turbines for automobiles must develop the high volume, low cost capability which does not now exist. This is a formidable task, but the potential payoffs in production are of far larger magnitudes than the development costs. The ceramic gas turbine has the potential to be the automotive engine of the future.

American "competitiveness" is a clear issue today and ceramic materials development is a current testing of American abilities to respond to technological challenge. I have just returned from Japan where I discussed "Ceramic Gas Turbines" with Government and industrial personnel. The Japanese thrust in 100kW (135 hp) automotive and 300kW (400 hp) ceramic gas turbines is large and truly threatens American leadership in this arena. Your willingness to continue and enlarge this high risk, high payoff technology area may well decide future American competitiveness in this crucial automotive arena.

THE CURRENT AND FUTURE U.S. CERAMIC GAS TURBINE PROGRAM

The current and near future United States ceramic gas turbine program is integrally coordinated through the U.S. Department of Energy

Office of Transportation Systems in Washington, D.C. Figure 2 shows that six efforts are operational to implement this activity and that the central goal is as follows:

> "Develop and demonstrate high performance, reliable, cost effective ceramic components in an automotive gas turbine engine environment."

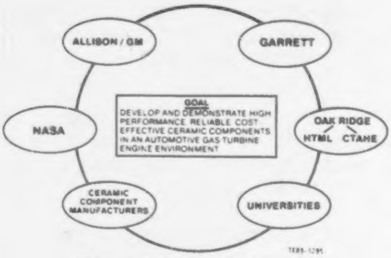
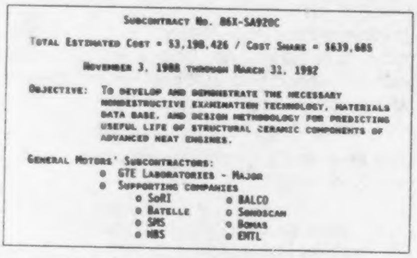

ALLISON / GM
GARRETT
GOAL
DEVELOP AND DEMONSTRATE HIGH PERFORMANCE RELIABLE COST EFFECTIVE CERAMIC COMPONENTS IN AN AUTOMOTIVE GAS TURBINE ENGINE ENVIRONMENT
NASA
OAK RIDGE
HTML
CTAHE
CERAMIC COMPONENT MANUFACTURERS
UNIVERSITIES
TE89-1295

Figure 2. DOE ATTAP/Materials Technology Team.

The two engine contractors are Allison Gas Turbine Division, General Motors Corporation and the Garrett Auxiliary Power Division of the Allied-Signal Aerospace Company. These two contracts are with NASA Lewis Research Center to demonstrate ceramic components in the GM AGT-5 engine and the Garrett AGT101 engine. Ceramic component development contracts are to be achieved with U.S. ceramic component manufacturers. GM and Garrett are to perform ceramic component material characterization and the capabilities of NASA, Oak Ridge National Laboratory (ORNL) and universities are to be utilized to support the engine teams in this task.

In addition to the two Advanced Turbine Technology Applications Program (ATTAP) contracts, a very significant materials development program administered by the Oak Ridge group is in place. This work is accomplished at Oak Ridge, several universities, ceramic component and engine manufacturers, and at other national laboratories such as the National Bureau of Standards, Argonne National Laboratories and the Army Materials Technology Laboratory. The Allison "Life Prediction Program" is one of the important projects sponsored by Oak Ridge and Figure 3 shows an introduction to this project.


SUBCONTRACT No. 86X-SA920C

TOTAL ESTIMATED COST = $3,198,426 / COST SHARE = $639,685

NOVEMBER 3, 1988 THROUGH MARCH 31, 1992

OBJECTIVE: TO DEVELOP AND DEMONSTRATE THE NECESSARY NONDESTRUCTIVE EXAMINATION TECHNOLOGY, MATERIALS DATA BASE, AND DESIGN METHODOLOGY FOR PREDICTING USEFUL LIFE OF STRUCTURAL CERAMIC COMPONENTS OF ADVANCED HEAT ENGINES.

GENERAL MOTORS' SUBCONTRACTORS:
- GTE LABORATORIES - MAJOR
- SUPPORTING COMPANIES
  - SoRI
  - BATELLE
  - SMS
  - NBS
  - BALCO
  - SONOSCAN
  - BOMAS
  - EMTL

Figure 3. Life prediction methodology for ceramic components of advanced vehicular heat engines.

The number of individual contracts outside ORNL in this materials effort is in excess of thirty (30) work statements and approximately twelve (12) work packages are being executed within ORNL. This work is supportive to the ATTAP program.

THE GENERAL MOTORS' ADVANCED TURBINE TECHNOLOGY APPLICATIONS PROJECT (ATTAP)

A five-year General Motors' ATTAP program was begun on 1 November 1987 and runs through December 1992. Figure 4 shows the schedule for the ATTAP program which is ad-

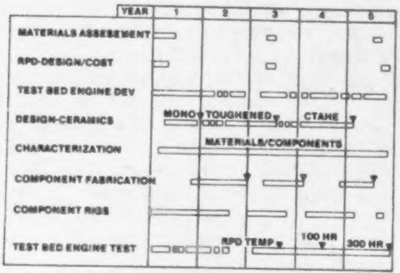


Figure 4. ATTAP schedule.

ministered by the NASA Lewis Research Laboratory, Cleveland, Ohio. This contract is with the Allison Gas Turbine Division, General Motors Corporation.

The ceramic component objectives for ATTAP are as follows:

- enhance development of analytical design tools
- develop improved processes for fabrication
- develop improved procedures for testing
- evaluate reliability and durability in an engine environment
- conduct 100 hours testing including operation at Reference Powertrain Design (RPD) conditions for design verification
- conduct a 300-hour engine cyclic durability test including RPD conditions

It should be noted that emphasis is on the ceramic components in the ATTAP project which assumes that basic turbomachinery aerodynamics and engine auxiliary systems were generated in the earlier AGT100/AGT101 programs sponsored by DOE. The exception is work required to eliminate combustion generated carbon (FOD) and modifications to the hot engine parts required by iteration between ceramic and mechanical design of ceramic components.

The truly critical technology needs which are the focus of ATTAP are as follows:

- reliable, cost effective ceramic components
- engine operation to 1370°C (2500°F)
- low emission, foreign object damage (FOD)-free combustion

Assuming ATTAP establishes these critical technologies, an automotive gas turbine should be feasible for industry which meets the following long standing goals of:

- 30% improved fuel economy over SI engines
- multifuel capability
- low emissions

Each of these goals has been the basic driving force for industry/government support for heat engine development.

It is to be noted that the ceramic component-design activity incorporates three distinct materials efforts (see ATTAP schedule, Figure 4). The first approach is to use monolithic ceramic components in the engines. The monolithic approach is believed to be the most cost effective approach envisioned for the automotive engines, and significant improvements in properties and toughness are now being made. Iterative design-fabrication-test should be able to permit monolithics to meet AGT objectives. The second materials approach is to use composite ceramics if the monolithic approach fails. This would include particulate, whisker and fiber, reinforced components to achieve toughness levels in excess of monolithic ceramics. Meeting cost objectives with these ceramic composite components will be very difficult. The third materials activity shown is to utilize the best technologies to evolve from the ORNL programs and to make ceramic components in the last year of ATTAP.

The General Motors ATTAP Engine

ATTAP requires an engine of proven reliability to evaluate ceramic components. General Motors selected the axial flow turbine geometry in the AGT-5 engine for ATTAP. Reliability accumulated in over 6,000 hours of AGT-5 engine operation on test stands and in automobiles meets the ATTAP objective of ceramic component emphasis. Also, the axial flow AGT-5 turbine maximum thickness is less than one-third the thick section in the radial inflow turbine. This should materially reduce rotor processing time and difficulty while promoting a much lower cost, high production volume rotor configuration.

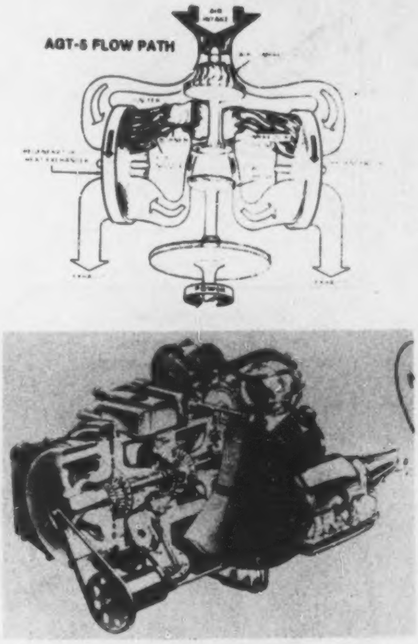


Figure 5. Axial flow test bed engine.

The AGT-5 engine is shown in Figure 5. The temperature out of the compressor is 204°C (400°F). Two ceramic regenerators elevate the compressor discharge air temperature to 955°C (1750°F) into the combustor, where fuel oxidation raises the combustor outlet temperature to 1370°C (2500°F). A single stage axial turbine drives the compressor, and a two stage axial turbine drives the gearbox and automobile. The regenerator hot side gas temperature is 976°C (1790°F) and the regenerator exhaust gas temperature is 273°C (525°F). These temperatures define the environment for ceramic components required in the 1370°C ceramic gas turbine.

The AGT-5 two shaft engine can be combined with an automatic, manual or continuously variable transmission to form a powertrain. The

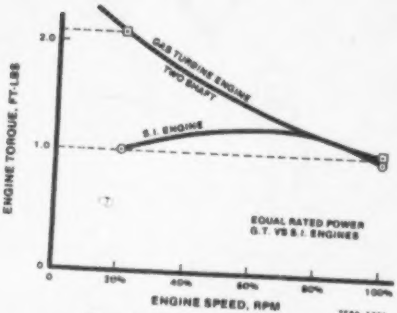


Figure 6. Engine torque/speed characteristics-- powertrain design.

characteristic torque curve versus engine speed is shown in Figure 6 for a SI engine and for the automotive gas turbine. The difference in torque characteristics and the response rate level for a given fuel flow change suggests that the turbine transmission should have a different configuration (including gear ratios) as compared to the SI engine and shows that a net powertrain is required for the automobile.

ATTAP is developing ceramic components technology to be verified in the AGT-5 engine. The AGT100 engine (Figure 7) put in place the initial automotive gas turbine ceramic com-

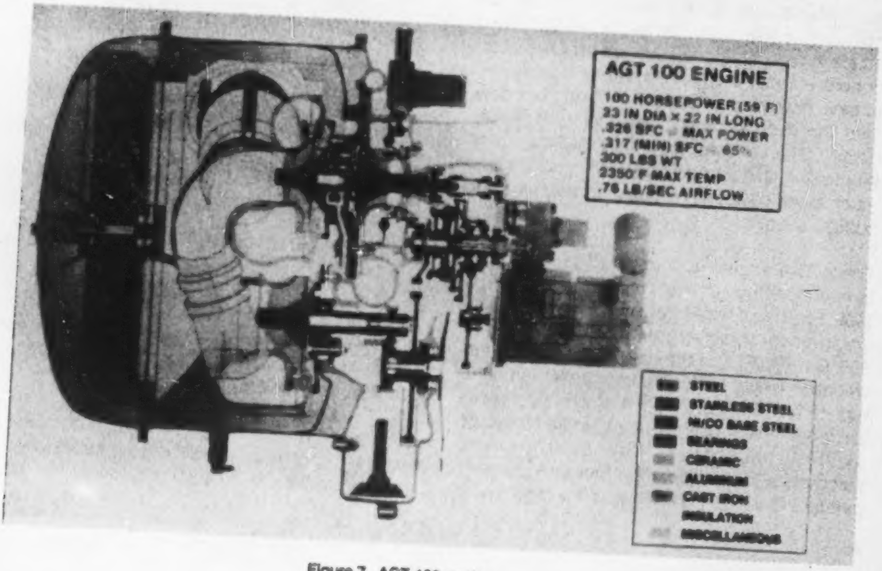

AGT 100 ENGINE
100 HORSEPOWER (59 F)
23 IN DIA × 22 IN LONG
.326 SFC @ MAX POWER
.317 (MIN) SFC @ 65%
300 LBS WT
2350°F MAX TEMP
.76 LB/SEC AIRFLOW
STEEL
STAINLESS STEEL
NI/CO BASE STEEL
BEARINGS
CERAMIC
ALUMINUM
CAST IRON
INSULATION
MISCELLANEOUS

Figure 7. AGT-100 engine.

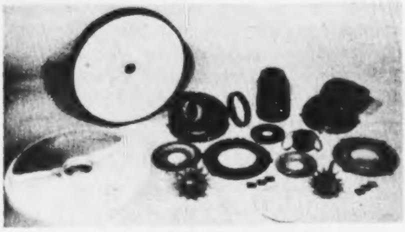
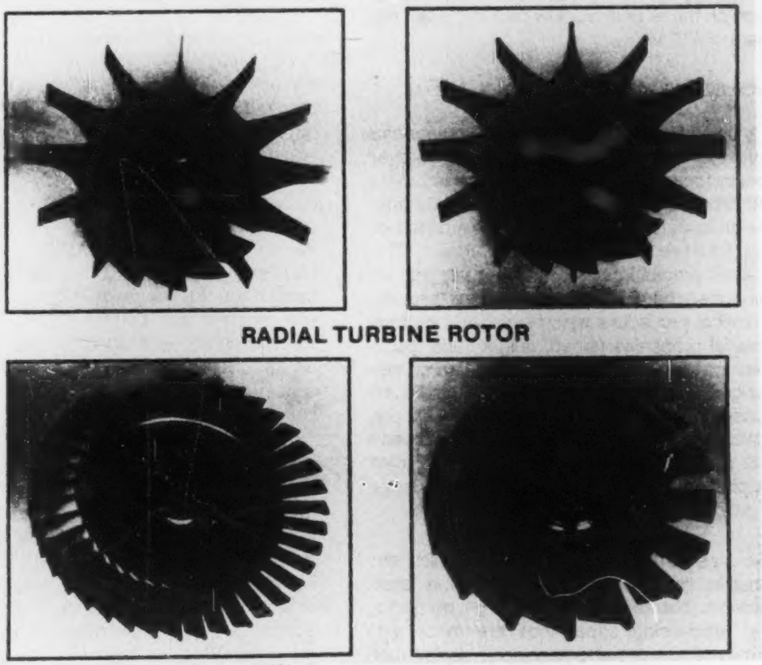


Figure 8. AGT-100 ceramic components.

ponent capability. Figure 8 shows the ceramic components developed in the earlier AGT100 project. The experience gained in making these 23 different parts translates directly to the ATTAP project. The parts for AGT-5 are smaller and less complex to make than were the AGT100 parts. Figure 9 shows the gasifier rotors for the two engines and illustrates relative size. The AGT-5 development components being emphasized in ATTAP initially are the gasifier turbine scroll, vanes, and rotor along



RADIAL TURBINE ROTOR

AXIAL TURBINE ROTOR

TE89-1302

Figure 9. Design iteration.

with the regenerator system. Additionally, a ceramic combustor is required. Later, the power turbine rotors, vanes, and shrouds will be added to the gasifier components for demonstration. The initial ATTAP engine will be run up to 1260°C (2300°F) with gasifier ceramic components.

Final engine running will be to 1370°C (2500°F) when the all ceramic flow path is used. This two-step temperature approach permits a rigorous screening of materials and processes in the early ATTAP activity with a more focused effort on the all ceramic flow path in the last two years of ATTAP.

Ceramic Component Development in ATTAP

The objectives for ATTAP ceramic components were stated earlier and pertain to improved design tools, improved processing, improved test procedures, and engine testing. Ceramic design to date has featured analysis based on fast fracture statistical procedures. This analysis procedure has been adequate, but experiences have suggested that a broader analytical procedure which includes long term material properties (creep, fatigue) and toughness may be very desirable. There are no new design tools as yet in place to enhance the classic "Weibull Theory". However, new life prediction methods are being probed in the overall U.S. program. This could be an area for international cooperation to expand initial design capability for ceramics.

The area of iterative design for ceramics also requires much optimization. In this area, tradeoffs between ceramic materials properties and processing capabilities are made with aerodynamics of turbomachinery, design margins of safety, heat loss in the engine and other mechanical and functional design features. A good example of iterative design is the tradeoff between aerodynamics (numbers of airfoils) and ceramic processing capabilities (dimensions and microstructure achievable) for turbine rotors. Judging criteria for this tradeoff study can be foreign object damage resistance, uniformity of strength and material toughness at critical stress locations within the rotor. Another example of an iterative design statement is the joining of metal shafts to ceramic rotors in the automotive gas turbine. In this case, the tradeoff studies compare various joining techniques and their strengths (joints) to configuration variations relative to heat loss, rotor balance and clearance control.

A crucial iterative design activity is the tradeoff between mechanical design of ceramic components and fabricability of ceramic components. In this case, the success of the ceramic component may be strongly influenced by such factors as thickness variations in component cross-sections, the flowability of slips into molds, the type of molds to be used in fabrication and many other factors. In all cases, the exchange of information between the ceramic component designer and the ceramic component fabricator very early in the design process is of extreme importance to successful ceramic gas turbine engine component running.

Ceramic Component Processing

The automotive gas turbine establishes several critical parameters to be achieved in structural ceramic components. The temperature capability of 1370°C (2500°F) has already been established. Life expectancy of 3500 hours of operation is a key criterion for the ceramic components. This life requirement in the hot flow path establishes several chemical stability needs such as oxidation resistance, resistance to chemical attack from the products of hydrocarbon fuel combustion (some of which contain trace elements such as sulphur, chlorine, sodium and other erosive/corrosive compounds) and the need to have resistance to long term strength factors such as creep and fatigue. Attempts to quantify short and long term required properties have been made in the past. However, the evolving basic materials technology has shown that initial goals established were not realistic. For example, initial strength goals for silicon nitride were chosen as room temperature strength at 85,000 psi and Weibull Modulus of 12. Current silicon nitride material strengths are being obtained at 125,000 to 150,000 psi and Weibull Modulus values of 15 to 20 are being reported. It is believed that optimizing basic starting powders coupled with new nearly isothermal component bake-out and sintering methods may produce strength levels of 200,000 psi and Weibull Modulus levels over 20 in the near future. The elimination of flaws and defects induced by processing should produce this result. Also, the higher strengths coupled with the elimination of failure sites in the basic ceramic components may reduce the so-called "toughness" requirement that many designers have used as a justification for not using ceramic components. The enlarging field of ceramic component fabricators has revealed very new and unique processing methods which show outstanding near term promise. A current goal for monolithic silicon nitride in the ATTAP program could be stated as follows:

M.O.R. strengths	Component strengths
R.T. = 150,000 psi	R.T. = 120,000 psi
1370°C = 105,000 psi	1370°C = 84,000 psi
m = 15-20	m = 15-20

It is desired to see an improvement of 30% in these values in the time period of ATTAP project. Microstructural controls within the ceramic processing activity is certainly a very promising methodology which deserves emphasis.

ATTAP Ceramic Suppliers

The Allison ATTAP ceramic supplier selection to address improved ceramic components is as follows:

- Carborundum Company-Niagara Falls, NY
- GTE Laboratories-Waltham, Mass.
- Garrett Ceramics Co.-Torrance, CA
- Corning Glass Co.-Corning, NY
- Ceramics Process Systems-Boston, Mass.
- Drexel University-Philadelphia, PA
- General Electric-Schenectady, NY
- Manville-Denver, CO

Each of these suppliers were given contracts and worked on improved materials and processing during 1988. In 1989 it is expected that AGT-5 ceramic components will be received and tested in the ATTAP program at Allison. An evolving matrix of candidate ceramic rotors is shown in Figure 10.

AIRFOIL NUMBER	20	15
CBO	SiC	SiC
GTE		Si_3N_4
GCC	Si_3N_4	Si_3N_4
CPS		Si_3N_4
DREXEL		SiC/SiC

Figure 10. Candidate ceramic rotor matrix.

Figure 11. Ceramic gasifier rotor development.

Illustrated in Figure 11 are rotors with 38 blades, 15 blades, and 20 blades. This activity illustrates the trade-off between aerodynamics, rotor blade stiffness, and rotor material selection and fabricability as we attempt to determine optimum geometry for foreign object damage (FOD) in the AGT-5 ceramic rotors.

A very large and expensive activity required to establish a mature design capability with ceramic materials is the establishment of an accepted data base for materials to be used in ceramic components. This data base evolution requires the testing of significant quantities of test samples with thorough analysis of failure causes. Correlation with nondestructive evaluation (NDE) and statistical prediction methods must verify predictability of material behavior in design. Thus, it is observed that standardization of test samples, test fixtures, loading rates, failure analysis methods and NDE methods would promote expedited accumulation of data on ceramic materials. It is believed that a cooperative effort between countries on data base accumulation is a fruitful area to pursue in the near future.

1988 Design and Testing Accomplished

The ATTAP schedule shows that a Reference Powertrain Design (RPD), Materials Assessment, Ceramic design, Materials characterization, Component Rigs and Test Bed Engine Test would be conducted in the first year. Each of these activities have occurred and a few of the results are presented for your assessment.

The first of these results is the RPD activity. Figure 12 is shown to illustrate the hypothetical fuel economy possible with a ceramic gas turbine in a 1988 Pontiac Grand Am automobile. Replacement of the standard Grand Am engine with a 1370°C (2500°F) gas turbine results in a fuel economy of 48.3 miles per gallon on diesel fuel (42.4 miles per gallon on gasoline). This is compared to approximately 28 miles per gallon

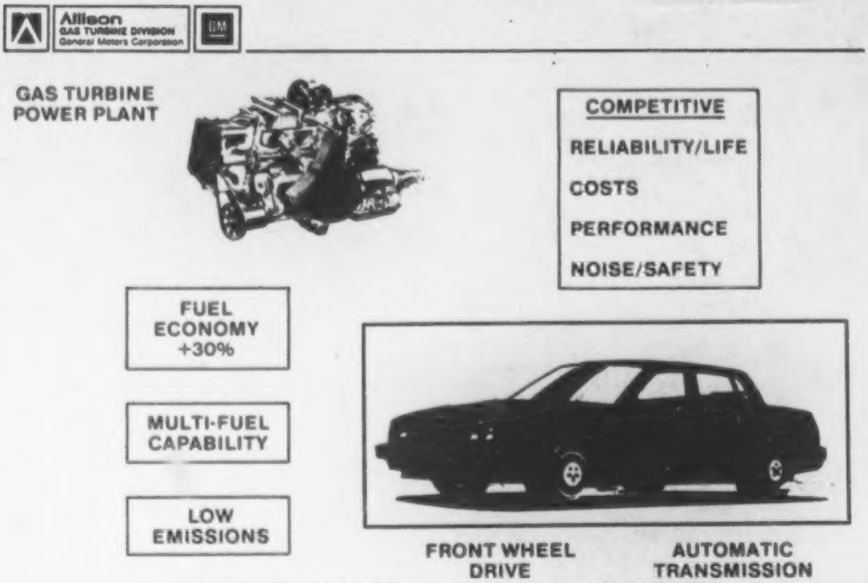

Allison
GAS TURBINE DIVISION
General Motors Corporation
GM
GAS TURBINE POWER PLANT
COMPETITIVE
RELIABILITY/LIFE
COSTS
PERFORMANCE
NOISE/SAFETY
FUEL ECONOMY +30%
MULTI-FUEL CAPABILITY
LOW EMISSIONS
FRONT WHEEL DRIVE
AUTOMATIC TRANSMISSION

Figure 12. 1988 Pontiac Grand Am with reference powertrain design (RPD).

in the current Grand Am or a 50% improvement in fuel consumption. This certainly illustrates the extreme importance that a future ceramic gas turbine may have in the highway vehicle scenario.

A second accomplishment of note in 1988 is the activation of a new hot gas generator rig at the General Motors Technical Center which is to be used in evaluating candidate ceramic rotors to be supplied by the ATTAP American ceramic suppliers. This rig will expedite early determination of the structural integrity of rotors made of different materials, of different geometry and by different processing methods. Figure 13 shows a picture of this rig which nearly reproduces an actual engine environment and the transient operation typical of an automotive gas turbine operating cycle. It is

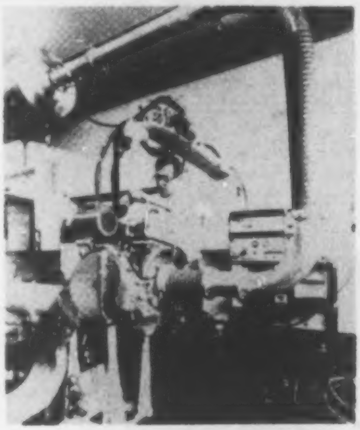


Figure 13. AGT-5 hot gas generator rig.

Table I.
Ceramic rotor testing in 1988.

	Total engine time (hours)	Total rig time (hours)	High time rotor (hours)
AGT100 (radial)	23	--	23
AGT-5 (axial)	391	77	330*

*322 engine hours, 8 rig hours

believed this rig will accelerate evaluation of rotors by at least a factor of three compared to full engine testing.

Engine testing of ceramic turbine rotors was achieved in 1988 in the AGT-5 engine and the balance of the AGT-100 engine testing was finished in 1988. Table I shows the engine testing accomplished and the most significant run is believed to be the 360 hours of engine running on a 15 bladed AGT-5 engine rotor. It is known that foreign objects including carbon generated in the combustion system and other debris from oxidized combustor liner metal and minor debris from insulation passed through this rotor in the 322 hours of test. After the test completion, no visible evidence of damage existed on the ceramic silicon nitride rotor. This is good news and begins to show that design iteration is equally important with improved material characteristics.

SUMMARY

The development of ceramic gas turbines has the potential to produce a future automotive powerplant offering significant conservation of fuel, multi-fuel capability in automobiles and reduced emission levels as compared to current automotive spark ignition engines. The establishment of cost effective production methods for automotive gas turbines is a major task requiring large expenditures but with potential payoffs far in excess of investment requirements. Perhaps a future vehicle such as the General Motors Chevrolet Express (see Figure 14), can capitalize on the ceramic gas turbine.

Achieving ceramic components in automotive gas turbines which will operate to 1370°C (2500°F) is the major initial technology goal to be accomplished to establish the practical reality of future vehicles with ceramic gas turbines.

Evolving improved ceramic components is a rapidly advancing ATTAP sponsored technology due to control of the chemistry of ceramics, improving powder making capabilities, improving green body and sintering processing methods and improving iterative design capabilities. This rate of improvement suggests caution in the extent of data base accumulation although established successful application

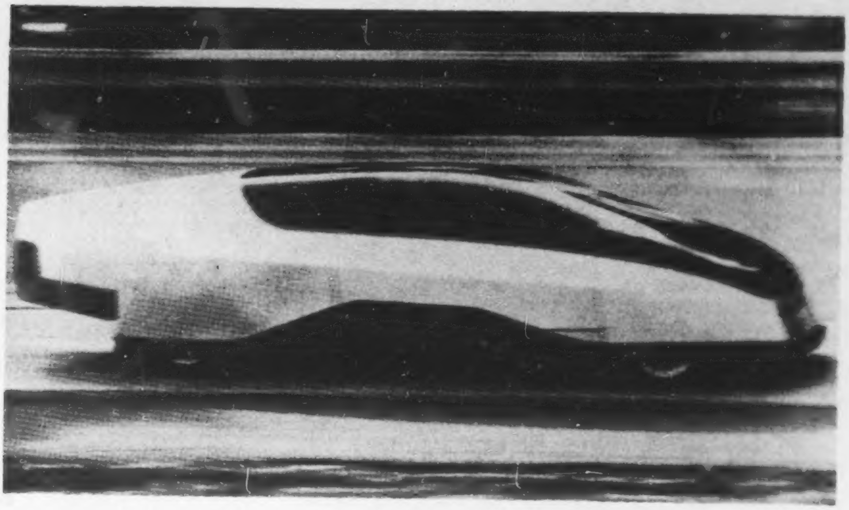


Figure 14. Chevrolet Express--research automobile with AGT-5 engine.

justifies pursuit of full data base characterization of the material. Turbocharger rotor successful materials are an example of materials justifying full data base generation.

Cooperative efforts between countries and within countries can expedite the generation of data base construction with standardization of test bar sizes, test fixtures and furnaces, NDE correlations with failures, generation of FOD characteristics, definition of chemical stability in standard environments, and interpretation of data relative to design. For example, data interpretation relative to design can yield many answers. Today, trying to establish a goal toughness number for ceramic gas turbines is considered to be very premature considering the state of the art in ceramic gas turbines even though it is known that improved toughness represents goodness.

It is recommended that cooperative exchange of nonproprietary data be expedited between the U.S., Japan, Germany, and other countries to accelerate acceptance of structural ceramics in the engineering and industrial communities. Table II shows candidate properties and standard approaches which could expedite acceptance of structural ceramics for ceramic gas turbines. This type of cooperation offers minimum duplication of effort, but most importantly it represents accelerated development of advanced products that can benefit all countries as we face pollution problems, fuel conservation problems and intelligent use of resources.

Table II.
Cooperative data base activities - structural ceramics.

Properties

- o Modulus of rupture
- o Elastic modulus
- o Coefficient of thermal expansion
- o Thermal conductivity
- o Specific heat
- o Poissons ratio
- o Oxidation

- o Tensile strength
- o Low cycle fatigue strength
- o Creep strength
- o Toughness
- o Density
- o Impact damage

Standardize

- o Test specimen size
- o Test fixture dimensions
- o Test temperature-ranges
- o Loading-heating rates
- o Interpretation of failure
  - o volume vs. surface
- o Numbers of samples (statistical control)
- o NDE methods
- o Preparation of specimens
- o Correlations-properties vs. microstructures
- o Standard environments

RECOMMENDATION

It is recommended that ATTAP funding for FY1990 be established at a level sufficient to maintain the two contractor approach DOE has contracted under this project.

Mr. Chairman, I would thank you for the opportunity to present these prepared remarks on the Allison ATTAP program. We sincerely hope this information is constructive and helpful to the deliberations of your subcommittee. I will be pleased to answer questions you may have or discuss further elements of my testimony if this is desired.

Mr. **Valentine**. Thank you, sir.

Mr. **Strain**. Could I interject one thing?

We were going to run a little experiment for you here to demonstrate the toughness of the ceramics.

Mr. **Helms**. I think you ought to do it because I think it is interesting. It is something we wouldn't have dared to do.

Mr. **Valentine**. Do we need to do anything, to bring out anything to protect the table or, I should say, the staff director?

[Laughter.]

Well, he is sitting up there.

What is the sticker price on that new Chevrolet you showed?

Mr. **Helms**. That particular one is about 3.5 million, but don't tell anybody I told you that.

Mr. **Boyd**. Mr. Chairman, members of the committee, one of the problems that we faced in developing ceramic materials for engines over the last 10 years has been a lack of understanding on the part of not only our levels of management but also other levels of management all the way up the ladder, the association in the United States of ceramics.

When we say the word "ceramics," we think of Indian pottery and we think of chinaware. The point that I would like to make today—you saw our engine, the AGT-101, set up here on the table, and I would like to point out that although they are brittle there are differences between houseware ceramics and engineered fine ceramics.

I would like to make that demonstration by taking a common deck nail that we have all used in our backyard and drive it into this four-by-four with this houseware.

[Demonstration.]

Since that didn't work, I would like to take this very elaborate, intricate piece of hardware out of the engine and drive that nail into the board.

Mr. **Valentine**. Does your Workmen's Compensation cover this?

[Laughter.]

This saucer must be made in Japan.

[Laughter.]

Is it brittle?

What about the protrusions on the lips? Is that a very brittle substance?

Mr. **Boyd**. It is brittle as well, but then we wouldn't hammer a nail with a metal turbine rotor either.

Mr. **Valentine**. Of course not.

We thank you, sir. That is a very dramatic display of what is taking place.

Mr. Nightingale.

STATEMENT OF MR. NOEL NIGHTINGALE, ASSISTANT GENERAL MANAGER, STIRLING ENGINE SYSTEMS DIVISION, MECHANICAL TECHNOLOGY, INC., LATHAM, NEW YORK; ACCOMPANIED BY MR. BRUCE GOLDWATER, VICE PRESIDENT AND GENERAL MANAGER OF MECHANICAL TECHNOLOGY, INC.

Mr. NIGHTINGALE. Thank you, Mr. Chairman. Accompanying me today is Mr. Bruce Goldwater, Vice President and General Manager of MTI.

Mr. Chairman, I have testified before this committee for many years, and I think I can safely say that the Automotive Stirling Engine Development Program represents a successful example of government-sponsored high risk technology development that has reached a point of completion and success by virtue of the support that we have received from Congress over many years.

The United States today is a world leader in Stirling technology, and although the automotive application remains somewhat illusive, we now have a technology base from which many other applications which are crucial to this nation are available to us—

[Slide.]

—such as space power, underwater power and propulsion, and stationary power.

I would be quite happy to answer any questions you may have in this area during the answer and question period.

However, my purpose here today is to give you the status of the Stirling automotive program.

The automotive program has achieved significant accomplishments over the past year.

[Slide.]

This is a summary chart. I will then go through a few pictures and graphs to expand upon these points.

The engine is fully built and tested. It has reached the efficiency and power levels that we had predicted. The last experimental engine in the program, called the MOD-2, has been installed in a Postal Service vehicle and will be tested in an EPA-approved facility next month and then will go on to field testing.

The fuel economy of the engine is better than the spark ignition engine, and there were two other major objectives that were established for this program at the beginning.

One was emission levels, and one was alternative fuel capability.

I have some graphs here I will show you of how incredibly low the emission levels are in the Stirling engine and how it is capable of operating on any fuel—gasoline, diesel, MTBE, methanol, JD-4, et cetera.

[Slide.]

Let me just expand on some of these points now by showing you first the Postal Service vehicle. Our engine was installed last May, 1988. That vehicle has been under test, with the Postal Service attending some of the test programs at MTI.

As I said earlier, it will be going to an EPA-approved facility next month and then will come down here to Washington, D.C. to be tested for an entire year by the Post Office.

[Slide.]

The next picture is a picture of another vehicle powered by a Stirling. It is a D-150 Air Force truck. That Air Force truck was here for a driving demonstration a year ago, and it has traveled all over the country, Florida, Texas, Nebraska, Colorado, conducting emission and alternative fuel tests.

The next graph—

[Slide.]

—is one of some data I would like to just take a few seconds to explain to you.

One of the problems in the altitude cities like Denver, Phoenix, Anchorage, Alaska, and other cities is that they have a high level of CO pollution. As you know, they literally have tons of CO per day dumped on the city.

Their solution to that problem with spark ignition engines is to mandate the use of MTBE fuel between the months of November and March to reduce the level of CO.

The top curve is the level of CO in the best spark ignition vehicle available to the people and the state of health in Denver, Colorado.

They were nice enough to take our truck and test it in an EPA facility. The lower line is the level of CO emissions coming from a Stirling engine, and that simply is just representative of one area of the country where they are solving emission problems by using alternative fuels.

The next graph—

[Slide.]

—is a demonstration of how the Stirling engine emission levels are on alternative fuels. We have done testing on gasoline, rig testing and lab testing on methanol and natural gas, and, different from the altitude cities like Denver and Phoenix, in the California, the Los Angeles area, their concern is NOX.

So the data over on the righthand side shows you why in the basin of Los Angeles they are turning to methanol to solve their NOX problems. That data is just simply to show you how low the level is when you test with the Stirling engine.

Incidentally, that truck that was shown to you has three gas tanks. It can test on gasoline, diesel, or methanol interchangeably, and those are the types of emissions that we get from the vehicle.

[Slide.]

On the next slide I would like to just emphasize that we have not stopped our endeavor to commercialize the Stirling engine. That is certainly the charter of the program. It is a rather elusive task, and over the past year, as we have in two years previous, we have been working with the end- users of vehicles, fleet operators mainly, who have to work in these urban areas and meet emissions standards, organizations like the United States Postal Service, the American Trucking Association, who lead us to groups like Federal Express.

We have been discussing vehicle demonstrations with the natural gas industry and, as I showed of course, the United States Air Force, who were kind enough to provide that vehicle and conduct the tests on their Air Force bases for us.

We have been pursuing a manufacturing base, of course, which is the key to the commercialization process. We are currently in discussions right now with three engine manufacturers, trying to establish some base. I would say that in preparation for that we have concluded this year a manufacturing cost reduction program of the engine with Deere and Company.

[Slide.]

Lastly, then, I would like to essentially make a point that when we started off in this program back in 1978 this nation really had no alternative. The heat engine bill was written and passed because there were no alternative power plants, and our charge was to come up with an alternative power plant, which I believe we have.

So through the Stirling technology you have an alternative technology that can provide the nation a mechanism to avoid dependency on foreign oil while maintaining a cleaner air environment.

In conclusion, Mr. Chairman, I would like to suggest that an FY '90 authorization of $2.5 million be provided to further the development of the Stirling technology, particularly on alternative fuels such as natural gas and to continue to work on this alternative technology to keep our air environment clean.

Thank you for this opportunity to come before you today, and I would be happy to answer any questions you might have.

[The prepared statement of Mr. Nightingale follows.]

Insert T.4

HEARINGS ON
DOE TRANSPORTATION PROGRAMS

Subcommittee on Transportation, Aviation, and Materials
Committee on Science, Space, and Technology
U.S. House of Representatives

Stirling Engine Program

Presented by:
Noel P. Nightingale
Assistant General Manager
Stirling Engine Systems Division

March 8, 1989

MECHANICAL TECHNOLOGY INC.

About the Author . . .

Noel P. Nightingale

Mr. Noel Nightingale is the Assistant General Manager of the Stirling Engine Systems Division of Mechanical Technology Incorporated, Latham, New York, a high-technology research, development, and manufacturing company. He managed the Stirling engine program almost since its inception in 1978 and has authored various papers on its progress. He has also been instrumental in transferring Stirling technology to industry and product users during the past few years. Prior to that, he was employed for more than 12 years with Pratt and Whitney Aircraft, a division of United Technologies Corporation. During that period, he undertook technical and managerial roles in the design, analysis, and development of military and commercial gas turbines and large (100 MW) ground power units. He also has management experience in multinational consortiums and aircraft maintenance. Mr. Nightingale holds a Bachelors Degree in Mechanical Engineering from the University of Toronto and Masters Degrees in Engineering Science and Business Administration from Rensselaer Polytechnic Institute.

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TESTIMONY ON THE STIRLING ENGINE PROGRAM

before

Subcommittee on Transportation, Aviation, and Materials

Committee on Science, Space, and Technology

U.S. House of Representatives

March 8, 1989

Mr. Chairman and members of the Committee, I am Noel Nightingale, Assistant General Manager of the Stirling Engine Systems Division of Mechanical Technology Incorporated. Over the years I have appeared before this committee to request support for the Automotive Stirling Engine Program. This program has been a successful example of government-supported, high-risk technology development. Through the unwaivering support of Congress the United States has established itself as the world leader in Stirling technology. Although the automotive application remains elusive, our fundamental base of knowledge has generated significant interest in the use of Stirling engines for space and underwater propulsion and power applications. Today, for example, MTI is working on a four-year program under NASA's Civil Space Technology Initiative (CSTI) high-capacity power initiative to develop a practical Stirling engine for future space missions. This interest is motivated by the fact that Stirling engines are more efficient than other power systems, resulting in lower system weights and, hence, launch costs. The engine's high efficiency and low noise profile are characteristics that make it attractive for military underwater application providing longer mission times and lower detectability, respectively.

It is the engine's ability to operate on alternative fuels like gasoline, diesel, methanol, ethanol, MTBE, and natural gas while maintaining lower emission levels than other engines that make the Stirling so attractive. The natural gas industry has expressed an interest in using Stirling engines operating on natural gas for stationary power generator sets, cogeneration, and chiller units. In addition, fleet operators such as the U.S. Postal Service continue to work with MTI on applying the engine to their vehicles because of its multifuel/low emission characteristics. I shall expand on this point later in the testimony.

I would like to take this opportunity to bring you up to date on the technical status of the Automotive Stirling Engine (ASE) program. During the past year, a Long Life Postal Service Vehicle (Figure 1) was equipped with a Mod II Stirling engine. Engine power and efficiency have met projections and, as promised, we fully expect the vehicle to meet the fuel economy and emission goals established for the program when it is tested next month at an EPA-approved facility. Following these tests the vehicle will be delivered to the U.S. Postal Service in Washington, D.C., to undergo field tests on actual mail delivery routes. For the test, the vehicle will be capable of operating on gasoline or diesel fuel interchangeably.

Most encouraging and exciting are the emission results when the Stirling engine is operated using alternate fuels. Over the past year, a Stirling power D-150 Air Force truck (Figure 2) was tested extensively on diesel, methanol, MTBE and JP-4 in addition to standard unleaded gasoline. Actual data with gasoline and MTBE measured in Denver, Colorado, where winter CO emissions are at unacceptable levels, showed that the Stirling vehicle had levels of 1 to 2 grams per mile,well below that of the best spark ignition vehicles (see Figure 3). Engine data at MTI indicates that CO emissions on methanol will be even lower. This improvement is directly attributed to the inherent advantage of the Stirling engine where CO generated at cold temperatures is emitted at much lower levels due to the more efficient combustion process. Whereas the ASE program was initially focused at reduced fuel consumption in passenger vehicles, today the ever increasing demand for clean air makes the engine an even more desirable powerplant for the future. As you know, stricter transit bus emission standards are proposed for the 1991 and 1994 time periods. Although the current Mod II configuration can meet all proposed standards, study of a larger Stirling engine for the bus application or a hybrid engine should be encouraged by this committee.

It is worthwhile pausing at this point to emphasize how important the support of Congress to continue development of Stirling technology over the past decade has been. The nation now has a technology that provides not only an

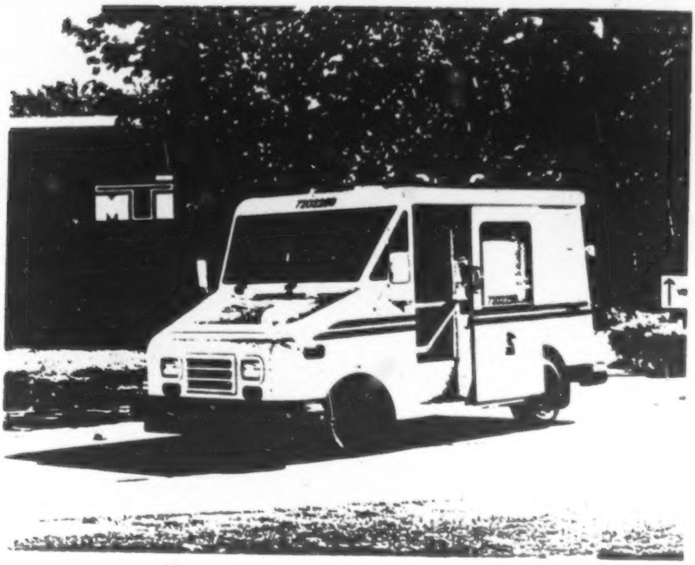


Figure 1 Stirling-Powered, Long-Life Postal Service Vehicle

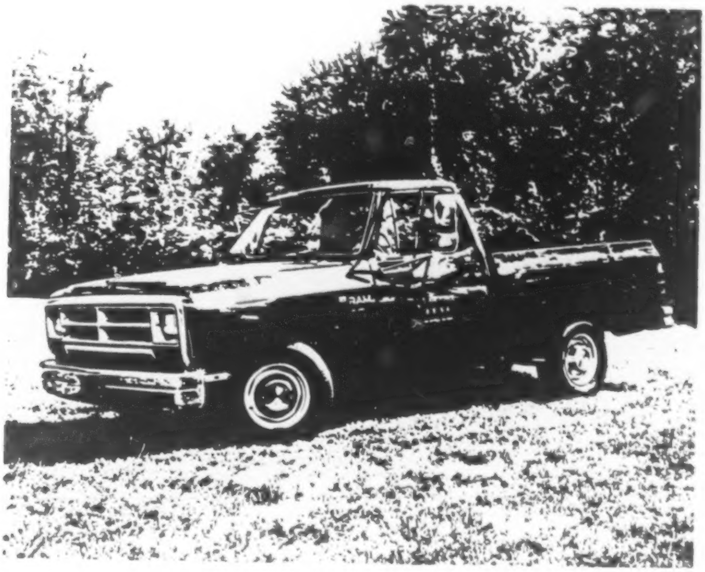


Figure 2 Stirling-Powered D-150 Air Force Truck

alternative to using standard fuels but also a solution to maintaining a clean air environment. The nation is no longer without alternatives in its quest to be less dependent on foreign oil and to keep our air clean.

MTI continues to pursue the commercialization of Stirling technology. Our strategy has been and continues to be to work with end-users to establish the market and to identify a means of manufacture. The D-150 Air Force truck referenced above was evaluated at four Air Force bases from Virginia to Texas. Over 18,000 highly reliable miles with an availability record of 94% were achieved. A number of fleet operators and the U.S. Postal Service have been closely monitoring the results of the test program.

To verify that, in fact, the engine could be manufactured at a competitive cost a value engineering/value analysis study was completed by Deere and Company during the past year. The study identified changes to the current Mod II engine design that have the potential to effect a substantial reduction in manufacturing cost.

The next step is to place into the hands of end-users multiple Stirling units for field test. American manufacturing industry is still reluctant to step up to a longer-term payoff, and so the process of commercializing this technology is painstakingly slow. While we are diligently pursuing many funding alternatives for this next step, we feel that the Department of Energy, encouraged by the success of this program, should support the maintenance of United States leadership in Stirling technology. A program to modify the Mod II engine for maximum efficiency, performance, and emissions reduction using natural gas as a fuel has been proposed. Such an effort would have support from organizations within the natural gas industry and would complement utilization of natural gas for fleets such as the U.S. Postal Service. An authorization of $2.5 million would support such an effort. As Figure 4 shows, CO emissions from a Stirling engine operating on natural gas would be even lower than that emitted from gasoline and methanol.

The Japanese industrial community is aggressively pursuing application of the Stirling engine for stationary natural gas fired heat pumps, chillers, and

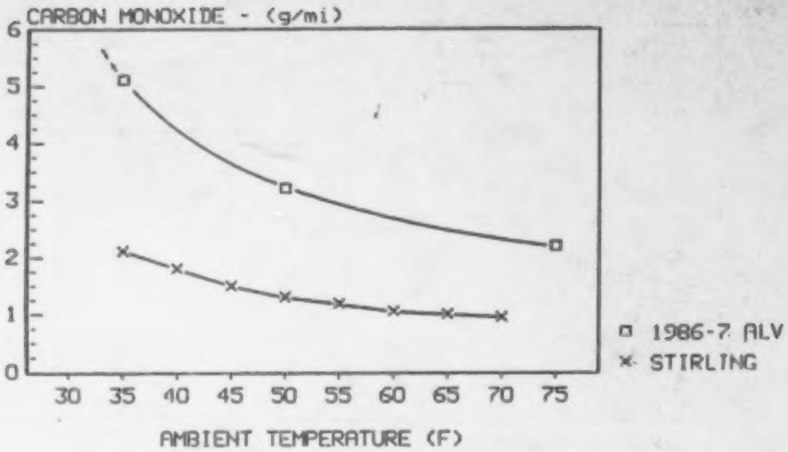


Figure 3 Temperature Effects on CO Production: Stirling vs Adaptive Learning Vehicles (11% MTBE Fuel)

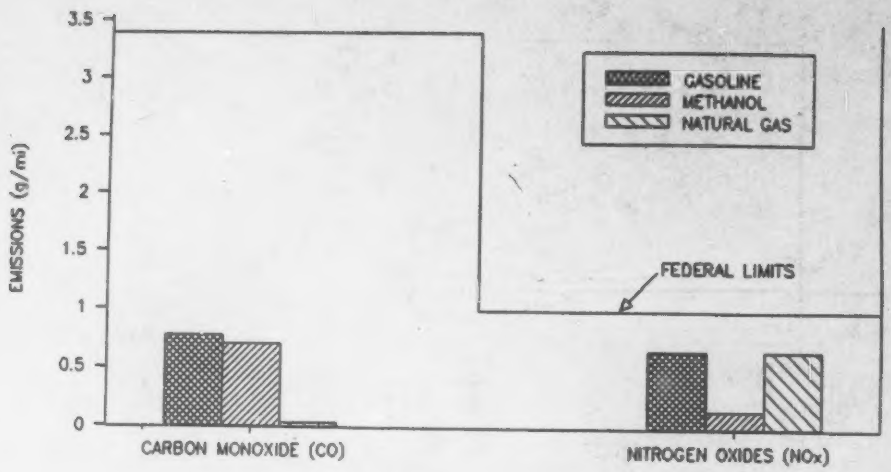


Figure 4 Stirling Engine Emissions: Alternative Fuels

co-generation units. To relinquish our leadership position, in again another technology, would be a serious letdown to the American taxpayer.

Mr. Chairman, I would like to thank you and members of the committee for this opportunity to testify before you today. I hope that this brief update has provided encouragement that we are as dedicated as ever to achieving the original goal of having the Stirling engine as a unique product of the United States.

Mr. VALENTINE. Thank you, sir, and thank all of you.

Let me ask this question to either Mr. Strain and/or Mr. Helms. In what ways has the ATTAP program benefited from maintaining both contractors, and what would be lost with a single contractor approach?

Mr. STRAIN. Both teams of course have been working since 1979. The two engine designs are different. The technology required is somewhat different, but to limit the technology development to one team would be very detrimental to this country, I think. With both teams, it has taken a long time to establish this technology base, and to lose part of it would not be to the best advantage of the country.

As you have noticed, the Japanese teams have a minimum of three people pursuing both the automotive and the industrial, and the European team is composed of five teams. So they also see the merit of doing that.

Mr. HELMS. To elaborate just a little bit on what Ed said, we now share data that we generate on the ceramics between the Garrett team and the Allison team. We do not stop there, of course. We also share data with the Oak Ridge National Laboratory and NASA efforts.

I think eliminating one of the teams would eliminate a real source of data that is invaluable to all of us. My advice is to keep both teams.

Mr. VALENTINE. Mr. Helms, other than the gas turbine engines, does GM have any plans for using advanced ceramics in other engines?

Mr. HELMS. Yes, sir. We, along with I think every major engine manufacturer, are beginning to test such things as ceramic valves, ceramic valve seats, piston caps, cylinder liners, et cetera, but on an entirely different basis as compared with what the turbine engine activity is.

Naturally, in the spark ignition and compression ignition engines the temperature exposure of the ceramic is only approximately half the level of temperature exposure in the gas turbine engine. So the spark ignition engine or compression ignition engine temperature requirements are far less severe than they are for the ceramic gas turbine.

Mr. VALENTINE. Would you be willing to increase your cost share to 30 percent?

Mr. HELMS. I would have to take that request under advisement, sir. I believe already our indirect cost share investment in automobiles that use the gas turbine and the investment in facilities, et cetera, far, far exceeds the 20 percent that we are putting in as a direct cost share with government today.

I would advise that we have a contract in place, both Garrett and Allison, that calls for a 20 percent cost share through the duration of the contract.

Mr. STRAIN. Could I add one thing there?

Mr. VALENTINE. Please do.

Mr. STRAIN. Also, this 20 percent is at the cost level. Many times in programs that we do for the government we are allowed to take credit for the fee that we would normally get on such a program, which runs from 8 to 10 percent on a typical NASA program. So in essence this really is a 30 percent cost level.

In responding to these kind of questions in the past, we have put together information for the committee and for the Senate people that showed our team—the suppliers as well as our team in facilities and other indirect support of the program matched the money being provided by the government.

Mr. HELMS. May I just again elaborate for just one second, please?

Mr. VALENTINE. Yes, sir.

Mr. HELMS. Both Garrett and Allison belong to a group called USACA, the United States Advanced Ceramic Association. This past year a survey showed that the costs being absorbed by the ceramics companies who are a part of the program is on the order of $157 million, I believe, sir.

So the cost shares that are present in the U.S. economy today in the automotive groups and in the ceramic groups is extremely significant.

I believe that your asking for additional cost shares at this time is ill-advised. I think that some people would be offended because of the extent of the support. Certainly, the government has been a tremendous catalyst in getting this ball rolling, and I would hate to see you put a roadblock in place by getting too high in your cost sharing requirements. I think it is very ill-advised.

Mr. VALENTINE. Mr. Nightingale, what happened to the proposed MTI/Deere joint effort to commercialize the Stirling?

You might have touched on that, on the efforts to commercialize this engine, but can you tell us a little more about this phase of it?

Mr. NIGHTINGALE. Yes, Mr. Chairman.

At this time last year we actually had to sign you in. As you know, the Deere Company was attempting to broaden their engine base from just diesels to alternative engines. Stirling was one of them. They had bought out the Curtiss- Wright Rotary Engine Division in New Jersey, and they had made commitments with that new engine about four years before they signed the agreement with us.

They felt, after reviewing, that their commitments on their new engine program and some of the emission problems with their diesels prevented them from taking on new obligations while they still had problems with their existing engine systems.

We still continued to converse with the Deere people. They have been very cooperative in working with some of these end-users, but they have had to back down from taking the lead of that team that we formed about a year ago.

Mr. VALENTINE. Thank you.

Mr. Lewis.

Mr. LEWIS. Thank you, Mr. Chairman.

I am going to ask Mr. Helms and Mr. Strain, I guess, both to respond on these. I am trying to find—you mentioned, Mr. Strain, I believe, that there were three Japanese companies involved?

Mr. STRAIN. Yes, in both the commercial and the automotive programs.

Mr. LEWIS. How much is the Japanese government contributing to this program? Do we have any idea?

Mr. **Strain**. That is shown on that chart I think you are looking at there. It is 124 million or so. It is shown on each program there.

Mr. **Helms**. I think if you average it over the nine years it is roughly $27 million a year.

Mr. **Lewis**. Do you think there is any technology that we should be working on for the internal combustion engine or any other type of engine with ceramics other than the gas turbine engine?

The Japanese are working in some of these areas, if not with the complete engine, with parts of the engine.

Mr. **Helms**. Mr. Lewis, we of course look at each of the different ways to apply the ceramics. The particular cycle that the engine uses in combusting the fuel is very important. The gas turbine is a continuous burning device. It likes to operate at very high temperatures, and as you go up in temperature, the thermal efficiency increases significantly, far more so than it does with either a spark ignition or a compression ignition engine.

I think we reflect in our testimony the potential of a 30 percent improvement in fuel economy with the use of ceramics relative to the spark ignition engine. We have the potential if we go from 2500 degrees Fahrenheit, which is our target level, to go to 3000 degrees Fahrenheit in the long term.

Now, we don't believe either the spark ignition engine nor the diesel engine can approach those kinds of thermal efficiencies, with or without the use of ceramics, and the basic reason is, is the type of cycle that is involved in the on/off ignition engines as compared to the continuous combustion engine. So the payoff in the turbine is far greater than it would be with other types of engines.

We need to continue, you know, development of all types of engines. I wouldn't say stop on anything, but I believe the biggest payoff for the ceramic materials is in the gas turbine engine, sir.

Mr. **Lewis**. That is a very good explanation, and I appreciate that.

Mr. **Helms**. May I make just one other observation?

I know that emissions are on the mind of all of us at this time. We are experimenting with different kinds of combusters on the gas turbine. We have tried what is called a diffusion flame type combuster, which is the type that is used in the aircraft engines that you fly on every day. We have tried the staged combustion system in the gas turbine. That provides improved emissions.

The pre-mix type combuster, where you can turn all the liquid fuel to gas before you oxidize the hydrocarbons, that provides by far the cleanest combustion we have seen, and it does provide NOX well below the federal standard. It does provide CO well below the federal standards. Should you burn on methanol. It is about an order of magnitude increase again in the NOX emissions, and there is a similar level of reduction in the CO emissions, and with the gas fuel you get far less unburned hydrocarbons than you do with the liquid fuel or even worse with the solid fuel.

So again the turbine offers real significant payoff in the fuel economy, with emission characteristics, and with multi-fuel capability because we have demonstrated that turbines can run on hydrogen, on methane, propane, ethanol, methanol, gasoline, diesel fuel, even dry micronized powdered coal. I think it is one of the few power plants that can achieve high efficiency on all those different kinds of fuel.

Mr. STRAIN. Let me just add one thing. That is without after treatment devices as well, no catalytic converters or anything like that.

Mr. LEWIS. Does General Motors, Mr. Strain, do they have any program looking at gas turbines for future cars outside of this area of research?

Yes, Mr. Helms.

Mr. HELMS. Do we have any turbine cars, sir?

Mr. LEWIS. Except in company proprietary information, I understand.

If you don't want to answer the question, I will leave it at that.

Are you working on other types of engines other than the spark igniter internal combustion engine?

Mr. HELMS. Will you forgive me if I say yes and I do not explain in too much depth?

Mr. LEWIS. That is fine, I understand.

Mr. HELMS. We are extremely interested in electric cars. We are extremely interested in fuel cells. We are extremely interested in all types of power plants. You know, we would be rather foolish not to look to all candidate propulsion systems for the future.

So the answer to your question, sir, is yes, we are. I hesitate to go into too much detail.

Mr. LEWIS. That is all right.

You both sound very excited about this engine. What do you feel is a level of funding that could provide the necessary research applications to bring the total engine forward within a reasonable length of time?

Say the Japanese are talking about nine. So we are talking about seven or six, and if we are not careful they will copy it anyway.

Mr. STRAIN. We recommended $6 million per contractor for '90, then an additional one to one and a half for NASA. That is to continue at the level we are on now. To complete the program would take about $34 million, including NASA's part. That would bring the ceramics to the point where we feel it could be commercialized and it could be picked up and gone forward with.

It would be highly desirable if we could work on all of the components in the engine and develop the engine to the point where it could be commercialized, but that would take considerably more money.

Mr. HELMS. I mentioned in my testimony that the emphasis in the current ATTAP program is on bringing forward the ceramic for the gas turbine. If you listened carefully to that statement, you will notice that we did not say anything about the rest of the power train or the rest of the system. In the original AGT program, that was bid and contracted through DOE. We did look at the entire system.

We were even to provide vehicles that would be tested and reported upon as we proceeded. Through the early years of the '80s, the vehicles were eliminated, the transmissions were eliminated, and the overall vehicle integration and control system, et cetera, were eliminated from the program.

I think what you have asked, sir, is to produce a useful, maybe a production-type vehicle, how much additional funds would be required.

My reply to you, sir, as an approximation, is I think it would be an expenditure level on the order of three times what we are applying today to address the complete vehicle system which integrates all technologies required to have a produceable automobile.

Mr. LEWIS. Do you feel that the present funding level and cooperative effort that you have, that we have an opportunity to meet our research goals at the same time the Japanese do? I don't want to be in a race with them, I am just using them as a time frame, but that we can be there at the same time that they are, before or after them, not counting the production model? Or are they looking at a production model with their level of funding?

Mr. HELMS. First, you know, they are just getting organized, in a way, and I observe a need to fight between Nissan, Mitsubishi, and Toyota. I would be happy to observe that.

I really believe that the Japanese effort is of significantly greater magnitude than ours. I think they will catch up with us if we do not increase our effort. I wish I had a crystal ball and I could tell you exactly how much we should increase it.

The thing I do observe is that you can see the numbers, you can see the number of team members that they have. These folks over there, when they set their heads to achieve something, they are pretty good at it. And I believe they have identified the real potential of this kind of engine for the automotive community. And we are in a real horse race, and if we don't identify with that, you will make a mistake.

Mr. WALKER. Would you yield?

Mr. LEWIS. I will be happy to yield to the gentleman from Pennsylvania.

Mr. WALKER. Don't the Japanese have an alternative—I don't think it's a turbine, but don't they have an internal combustion ceramic engine that they have run? I don't know how successfully. But don't they have something on the test track?

Mr. HELMS. If I may, please, we have an association with the Isuzu people and some of the other companies like Toyota. They do indeed, they have applied ceramics in their diesel engines and their spark ignition engines, and they have not gotten the kinds of payoffs that were predicted originally for the ceramicized spark ignition and compression ignition engines.

I would observe with you that they also have operating gas turbines in vehicles today. At Toyota I personally drove a gas turbine-powered bus and a gas turbine-powered automobile. Now, those were metal types of turbines. They have not integrated the ceramics into their gas turbine engines to the degree that we have. Nor have they practiced the design methodology that we have.

But they are producing some excellent ceramics, probably better than those that we can acquire in this country today.

So, it is a matter now of them beginning to address system application, total engine and operating characteristics, as well as introducing these ceramics into their engines.

Mr. WALKER. If you would yield further just for a moment.

In other words, they are at the point that you say that we would have to raise our level three times the present level in order just to achieve. You mean the Japanese are already there, they have running vehicles out, in a couple of cases with spark ignition and so on, they have run ceramic engines, and we at this point do not have the capability due to the budget restraints that we have here of even moving to that level of development?d

Mr. **Helms**. I think that is correct, sir.

Again, when I answered three times, I thought I was addressing Mr. Lewis' request to have something that would be running in seven years instead of nine years.

If you have withdrawn that restraint of seven years, maybe we would back off to two-to-one. I don't know the exact numbers to quote to you, but those are the kinds of approximate answers I would give you, sir, yes.

Mr. **Walker**. But the Japanese are there now?

Mr. **Helms**. They are not ahead of us, sir. I am telling you that in the diesel engine and spark ignition engine they may be ahead of us in applying ceramics to items like valves, valve seats, wrist pins, et cetera. I think they are ahead of us in that respect.

I think they are way behind us in the turbine activity, even though they can process well the ceramic components, they have not actually designed engines that are suitable for ceramics. They have metal engines. They now have to adapt the ceramics, and I believe that Garrett and Allison are ahead of the Japanese relative to the engine and the application of the ceramics in gas turbines.

Mr. **Walker**. Would the gentleman yield further? I would not impact on his time.

Just one question on that. Their metal turbine engines, where are they with regard to metal turbine engines that we rejected about five or ten years ago as being inapplicable to passenger automobiles in this country? Are they ahead of that curve or are they behind it?

Mr. **Helms**. They are about in the same position. Their operating temperatures in their current metal gas turbines are 1050 degrees centigrade, which is about 1900 degree Fahrenheit turbine.

Mr. **Walker**. So, they are approximately comparable to the 50 turbine engine cars that Chrysler put on the road in the mid-'70s?

Mr. **Helms**. I think they are better than those. That was the mid-'60s, sir, and you know time flies when you're having fun.

But those engines that Chrysler put on the road operated at around 1700 to 1725 degrees Fahrenheit, about 900 degrees C. So, the Japanese are ahead in that state of the art.

Mr. **Walker**. You all built a CIRV car in the late '60s or early '70s. General Motors had an experimental car that they called CIRV that had a turbine engine in it.

Mr. **Helms**. Many experimental cars. Right today I have five different cars that have gas turbines in them. But I do not identify—

Mr. **Walker**. It was a high-performance car.

Well, never mind. I am sorry. Thank you.

Mr. **Lewis**. Thank you.

I am very much excited about this ceramic program as well.

Mr. Chairman, I have a couple of questions for Mr. Nightingale.

Mr. Nightingale, in the past we had not had any U.S. automobile manufacturers interested to a great degree in your engine. Have you found that different today?

Mr. NIGHTINGALE. Not entirely, Mr. Lewis. That has not been for lack of trying. We went to Chrysler last June. We tried to get back into General Motors at the same time.

There is not enough of an incentive for them to take the risk and the tooling costs associated with going with an entirely new engine series.

We find that there is a great deal of respect for the gain made in the Stirling, but to take that commitment to move into a new engine family just isn't there yet.

That is consistent with our strategy that I indicated on one of my viewgraphs where we are trying to deal with the end users who are in a niche of the market and having to deal with either very complex emission problems in the fleet or the use of alternative fuels in the fleet and create that demand such that the manufacturers will see the market and supply it. That has been our alternative strategy.

Mr. HELMS. May I just correct one impression that I got out of the current statement. I believe that in looking at the Stirling engine, that our corporation's many issues—supply infrastructure, the safety issues, performance issues, et cetera—the Stirling engine presents some rather unique situations as compared to the current infrastrutcural system that exists for transportation in this country today.

Not the least of those are the issues that are involved in working with the heat transfer medium in the Sterling engine, the hydrogen. I would hate to have you get the impression that General Motors is not receptive to new power plants if they offer good payoff.

The Stirling engine today, because of infrastructural considerations, safety issues and other issues, does not offer payoff. There are other engines that may offer payoff within a much better within a much better and positive way than does the Stirling engine.

So, we will at GM advance to be competitive in the marketplace as it is justified with proper payoff and proper business considerations. The Stirling does not satisfy those requirements today.

[Material referred to follows:]

MECHANICAL TECHNOLOGY INC.

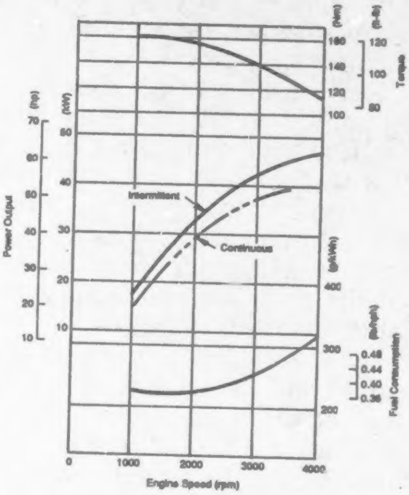
MOD II

Stirling Engine for Industrial Use

Engine Description	
Type:	Stirling, 4-Cylinder, Vee, Water Cooled
Cylinder: Bore × Stroke:	73 × 30 mm (2.07 × 1.18 in.)
Piston Displacement:	0.502 Liters (30.3 cu in.)
Direction of Rotation:	Counterclockwise Viewed from Flywheel
Dimensions (L × W × H):	Approx. 800 × 925 × 820 mm (31.5 × 36.4 × 32.3 in.)
Dry Weight:	Approx. 201 kg (443 lb)

Features	
Cylinder Block:	Single-Piece Cast Iron
Heater Head:	Iron-Based Alloy Casting with Inconel 625 Heater Tubes
Low Maintenance Items:	• Single Igniter -- Fires Only During Start • No Oil Changes Required
Multifuel Capability:	Any Petroleum or Alcohol-Based Liquid Fuels, Propane or Natural Gas with No Performance Change

Performance & Performance Curve (STD. specs)



Generator Use (SAE J1349 Gross)			
Stand-By Power		Prime Power	
Output at 1500 rpm kW (hp)	Output at 1800 rpm kW (hp)	Output at 1500 rpm kW (hp)	Output at 1800 rpm kW (hp)
26 (36)	31 (42)	22 (30)	27 (36)

General Use (SAE J1349 Gross)			
Output, Intermittent Rating kW (hp) at rpm	Output, Continuous Rating kW (hp) at rpm	Maximum Torque Nm (lbf-ft) at rpm	Minimum Fuel Consumption g/kWh (lb/hph) at rpm
47 (63) at 4000	41 (55) at 4000	161 (118) at 1000	222 (0.363) at 1200

Mr. LEWIS. Thank you Mr. Helms.

We were aware that the cost performance reliability was a big question mark. Thank you for your explanation.

Mr. Nightingale, we observed your engine in that Air Force pickup truck and at the Oshkosh air show last August. You did have some torque and acceleration problems with that engine. Have you corrected those problems?

Mr. NIGHTINGALE. Yes. The truck itself was equipped originally with 145 horsepower diesel engine and the Stirling engine that is in it is an 80 horsepower. So, you have the truck literally is too big for the engine. But that can be partially solved through selection of the transmission and some of the control variables that we can change in the engine such that the acceleration is approximately zero to 60 in 20 seconds. In the original truck it was around 16 seconds. So, it's about four seconds off.

Mr. LEWIS. I think you have some problems with it before, not only with that pickup truck, you had it on the test bed, these same kind of problems if I am not mistaken.

Mr. NIGHTINGALE. Yes. That truck has literally driven from Austin, Texas, back here to Washington, D.C. We have had no problems with it since those earlier test problems. It has been very reliable, over 20,000 miles.

Mr. LEWIS. Have you looked at any foreign countries that produce road vehicles that use the Stirling engine? Have you tried to market them elsewhere outside of the United States?

Mr. NIGHTINGALE. We have been reluctant to do that, Mr. Lewis, because of the fact that the technology and the lead was attained through you. And we have taken instead our charter to find out exactly what is going on in foreign countries. I participated in an international energy agency group with the Department of Energy—that was over in Japan—and saw a Toyota Corolla equipped with a Stirling engine.

Toyota is working on Stirling engines. And I won't limit that to automobiles. In fact, they are using them for stationary heat pumps, chillers, and so forth. Mitsubishi is also doing the same.

We did not see any evidence in Honda and Nissan of any work with Stirling engines in vehicles. There is a great deal of use, though, of Stirling engines in some other applications other than transportation.

We know that the Russians are starting to experiment with Stirling in submarines because of their quiet operation and their efficiency.

We know that the Germans have been working on Stirling for military purposes for the last decade.

And as I said in my opening remarks, had it not been for your support over the past ten years, we would not be sitting here today with that technology and utilizing it in other areas in our own country here. The credit goes to your support.

But we have not pinpointed any specific automotive company that is working on Stirling in cars at this point.

Mr. LEWIS. You did, mention and we did know, that the Stirling does lend itself to stationary power plants, that sort of thing. Have you looked at that market for the Stirling?

Mr. NIGHTINGALE. Yes, very much. In fact, we have put together a business plan and have had extensive discussions with the gas industry on both commercializing to utilize natural gas both in vehicle and stationary applications. The engine fundamentally remains the same, it is just the packaging around it. We are looking very seriously at that right now.

That is what led me to my last viewgraph, which was we just need some support while we are going through that transition period.

Mr. LEWIS. Thank you, Mr. Nightingale, gentlemen.

Thank you, Mr. Chairman.

Mr. VALENTINE. Mr. Rohrabacher?

Mr. ROHRABACHER. Mr. Helms, the cost of ceramics as compared to the cost of metal, in the end is it going to be much cheaper to have the ceramic parts than to have the same metal parts in terms of the actual material itself?

Mr. HELMS. Yes, sir. We feel that at a mature state, that the ceramics can probably be acquired at something like a third to a tenth of the cost of the current super-alloys that are typically used in gas turbines.

If you asked me today how much I would pay for a ceramic piece like that one, it is excessive because we are putting the technology into place. But the thing we have observed already is a decrease in price as we discover new processing for both the basic housing and the manufacture of the actual component.

Mr. ROHRABACHER. We have been in a cycle now in terms of this basic research and development to come to the point where you will actually be able to produce things at a profit. How much has the Federal Government committed to this project over the years?

Mr. HELMS. It depends on how far back we go, sir. I believe it is approaching $100 million with our company. And I suggest it is approaching $70 million—well, 210 total.

Mr. ROHRABACHER. At what point do you think we are going to reach the time which you project into the future when the Government ends this cycle, they are going to start a new cycle and the Government is going to be out of it and is going to be out of the subsidy cycle and into the profitmaking cycle? Two years? One year? Next year?

Mr. HELMS. To be perfectly honest and candid with you, sir, I believe it is going to be another three to five years that you will see a necessity to continue to develop and to develop in place the kind of technology that you have already got going.

You noted on the chart that I showed that there is a major effort at Oak Ridge, new processes, new powder-making capabilities coming out of that effort. The effort that we have at Garrett and Allison is still on the steep part of the learning curve on how to iterate and choose between geometries.

I believe another three to five years we probably will be in a position where we can take off on our own, kiss the Government goodbye, hopefully be leaders in the world relative to the ceramic industry.

Mr. ROHRABACHER. So, for the next three to four years I am going to be seeing you here?

Mr. HELMS. I am as eager as you are, sir.

Mr. ROHRABACHER. This is my first year here. I will be looking forward to following your progress.

Mr. Nightingale, about the Stirling engine, how much money has the Federal Government put into the development of the Stirling engine?

Mr. NIGHTINGALE. About $110 million over the past ten years.

Mr. ROHRABACHER. When do you expect—you are here asking for a couple of million dollars. What are you asking for this year?

Mr. NIGHTINGALE. $2.5 million.

Mr. ROHRABACHER. $2.5 million. When do you expect to be in the profitmaking cycle and no longer asking the Federal Government to subsidize your operations?

Mr. NIGHTINGALE. As I mentioned to Mr. Lewis, we have put together a business plan, and the business plan projects that it will take us three to four more years to be in a preproduction phase.

And of course, we will have to raise equity, and we are not going to be coming to Congress for this. But the total package will take approximately $15 million. We testified to that effect last year. It is a laid-out business plan, and we are in the process of doing that.

Mr. ROHRABACHER. Your engine, you have already received all this money from the Government. When did that subsidy start?

Mr. NIGHTINGALE. 1978 was the start of the program.

Mr. ROHRABACHER. Back almost when I was in my 20s.

Mr. NIGHTINGALE. We all started off together, the gas turbine and Stirling.

Mr. ROHRABACHER. After all this time and all the money, you still think it is going to be another three years. Is there some reason that we should think that you are going to be as competent in terms of reaching this goal in three years as you have not been in the last ten years?

Mr. NIGHTINGALE. Yes. I think I should qualify my statement by saying that we have met the original goals of the program we started ten years ago, which was to develop an engine for the automotive application, running on unleaded gasoline and meeting the emissions standards.

I think the thrust of today has reversed somewhat from the concern for conservation and is more towards the use of alternative fuels and emissions levels.

My request is to continue that.

Mr. ROHRABACHER. You have met your goals, but you are still on the subsidy? You are still asking for money. That doesn't make much sense to me. The goal should be that you are not here asking for money. Isn't that part of the goal? How can you tell me that you have met your goals if you are still here asking us to give you taxpayers' money?

Am I being too harsh on you? This is my first time out here. It just seems to me that when somebody comes to us asking, you know, I was in the private sector and if somebody asks you for something you expect to get something after a period of time and not seeing him anymore.

Mr. NIGHTINGALE. Let me say that we are probably suffering from the fact that we are successful and the conditions in the Nation have somewhat changed from where we started off. And I think that there is still a need for work relative to alternative fuels and relative to clean emissions and that you have a power plant. There is a large investment.

I will go back to your original question. You have invested $110 million in the technology. We are in the process of commercialization. We are the leaders in the world. What I am saying is we should continue to work on that and maintain that lead and position ourselves better for what our needs are today, which is alternative fuel operation and low emissions.

Mr. ROHRABACHER. If you have reached your goals and you have got this thing developed now, and if there is a commercial application, is the private sector so dumb that they are not going to be able just to come up with the money that you need?

I mean, I do not understand why you are here if it is profitable, if it is going to be a profitable venture, why you are not out there raising some money from somebody who wants to make a profit investing in your technology.

Mr. NIGHTINGALE. We are doing that. I think I should separate the fact that the business plan and the private sector equity and the entire thrust will be funded by them to establish the business and begin to make a product.

What I am suggesting here is that we should not stop furthering technology, improving upon the technology. The $110 million invested in the technology of the Stirling engine is a drop compared to the billions put in the spark ignition engine and the diesel engines at this point in time.

And what I am saying is we basically have a Stirling engine that is comparable to a Model T, and that we have still a long ways to go and if we don't continue to advance the technology and alternative fuels like natural gas, that we will quickly find ourselves buying Stirling engines from Japan.

Mr. ROHRABACHER. Americans don't have that same profit instinct that the Japanese do?

Mr. NIGHTINGALE. Unfortunately, no. I didn't say to you that we have been approached by the Japanese, and we have resisted that to try to get American industry to step up to a Stirling industry rather than sell it overseas.

Mr. LEWIS. If the gentleman would yield?

Mr. ROHRABACHER. I sure will.

Mr. LEWIS. Do you have a set of performance specs on the Stirling engine you could provide this committee?

Mr. NIGHTINGALE. Yes, Mr. Lewis. The performance of the Stirling engine in the automobile, which were the primary goals, yes, acceleration times, mileages, emission levels, yes.

Mr. LEWIS. Horsepower BHP and all that stuff?

Mr. NIGHTINGALE. Would you like that, Mr. Lewis?

Mr. LEWIS. I would like you to submit it to the committee because you did mention earlier—if the gentleman would continue to yield—the reason for the $2.5 million was not to improve the engine itself but to improve, to check the work on the various fuels for emissions. And you did say that what you do have is a Model T Stirling engine.

So, I am very disappointed if Congress financed you to come up with a Model T Stirling engine.

Mr. NIGHTINGALE. What I meant by that, Mr. Lewis—I think I should qualify that—is to move forward now with the engine as it is currently designed requires a manufacturer.

If we are going to be successful in the commercialization, we need to involve a manufacturer in how to basically take that design and that specification which you are calling for and turn it into a viable cost- competitive product.

I do not think it is the place for this type of program or your types of programs under this committee to ask for that kind of funding.

So, what I am saying is that we must go out to industry to take it from the Model T stage to an advanced engine design. And I am not suggesting that we do anything with that 2.5 relative to that.

Mr. LEWIS. Thank you.

Thank you.

Mr. VALENTINE. Before I recognize Mr. Walker, let me say to the gentleman from California that it is a tradition in this subcommittee to engage in aggressive cross examination. And I think there is a presumption that the witnesses who testify here have the wherewithall to defend themselves. And as long as the committee members do not use any profanity that the staff can't understand—

[Laughter.]

Mr. VALENTINE. And as long as you don't say anything about the queen, I was going to say the speaker, but I said the queen.

Mr. Walker?

Mr. WALKER. Thank you, Mr. Chairman.

Mr. Nightingale, I am somewhat sympathetic with your position. With regard to American industry, I remember that American industry turned down the rotary engine too, and Mazda did a pretty good job of putting the rotary engine on the road. It was fairly successful not only in a passenger car, but it has done quite a job of racing it with great reliability. So, we have not always adopted new technologies.

Give me some idea, if you would, about the level of performance. I understand that you will provide it for the committee, but you have approximately an 80-horsepower engine, did I hear you say earlier?

Mr. NIGHTINGALE. Yes, sir.

Mr. WALKER. An 80-horsepower engine installed in a 2000-pound car would go from zero to 60 how quickly?

Mr. NIGHTINGALE. In a 3000-pound car?

Mr. WALKER. In a 2000-pound car.

Mr. NIGHTINGALE. You don't need 80 horsepower for a 2000-pound car.

Mr. WALKER. 2000, 2500 pound. A 3000-pound car is getting to be a fairly large car. I drive a Sierra, for example, and it weighs about 2800 pounds. You know, it's a fairly heavy vehicle for that size vehicle. That is what I am looking at. I am looking at that 80-horsepower engine in something like a Honda Civic. That is somewhere between 2000 and 2500 pounds. I don't know exactly. 2200 pounds, something like that. How fast? What would your acceleration time be?

Mr. NIGHTINGALE. The acceleration time from zero to 60 would be between 10 and 12 seconds.

Mr. WALKER. What would be the mileage that that car would get with that kind of performance level?

Mr. NIGHTINGALE. It would be pushing about 50 miles per gallon on the highway and probably around 27 or 28 miles per gallon in the city.

Mr. WALKER. Now, help me to understand how that is better than what they now have. You have given me performance times. That is slightly less than the acceleration time that a Honda Civic now gets. It is also about the same relative mileage that a Honda Civic now gets. Explain to me where we are getting an advantage out of the Stirling by adopting that technology.

Mr. NIGHTINGALE. I think if you took the numbers and averaged them, you probably would find that those numbers I quoted you were still on the order of 15 percent better in fuel economy, but I will certainly accept your question, you know, with the fact that the Stirling is slightly better in the fuel economy but it is certainly not worth footing a half a billion dollars into tooling to manufacture.

The point that I think I was trying to make was the fact that throughout this country we are finding areas in which we have a very severe emissions problem and that in order to solve those problems, be it to corner that part of the country to the point where it has to use a particular fuel or to force operators or the public to buy cars which have additional emission equipment on them to meet lower standards which are projected for 1991 and '94, that all of those now will be costly and cause maintenance problems, reliability problems, and the Stirling engine would then come out.

Mr. WALKER. Are you saying the Stirling engine will be better, for instance, the regime you are going to go to on emissions, solid-state electronics, which will be fairly reliable, I mean just by the nature of it, and you know, they will heavily computerize that.

Now, is the Stirling engine—that obviously is something that they can do relatively inexpensively, depending upon what your computer program is. It can be a fairly simple program for emission levels. Is your Stirling going to be better than anything that we can produce with essentially electronic gimmicks?

Mr. NIGHTINGALE. Yes. I guess I would go back to the graph I showed in my testimony where the testing in Denver, for example, showed that with the best spark ignition engine, with the best fuel injectors, with the best electronics, that when the ambient temperature lowered, then the CO emissions were twice the value.

And that was in the best possible optimization of the engine, whereas the Stirling was one-third that value.

When you talk about going into the cities—

Mr. WALKER. Let me come back. When you say "best available," that's best available in production, or was this the upgrade that we are going to see in the early '90s when they go to the new electronics?

Mr. NIGHTINGALE. These are experimental vehicles today, not production vehicles.

Mr. WALKER. So, in other words, they were using the new solid-state computer technology that we will be using in the early '90s for emissions control?

Mr. NIGHTINGALE. That's right. If I could just quote you a number on that particular graph.

At about 40 degrees Fahrenheit a normal carbureted engine would have been 50 grams per mile, and some of the existing engines today with the best fuel injectors and electronics are perhaps getting around 10 grams per mile, the data I showed you was five grams per mile because it is in fact the most advanced research type of vehicle that they can get data on.

And if you see the Stirling, it was down around two. That doesn't look like a heck of a lot. You say, well, what's four grams per mile? When you multiply that by half a million people, you find that you are talking about tons of pollutants per day on a particular city.

My only point is where back in the middle of the '70s, when we had an oil crisis on our hands and we had no alternatives and Congress passed the Heath bill to try to come up with an alternative, you now have an alternative today. And I would not suggest that we stop working on that alternative.

Mr. WALKER. So, if I understand what you're saying, the Stirling gives us very little, if anything, in the way of performance improvements, but it gives us a significantly lower emissions, based upon your testimony?

Mr. NIGHTINGALE. Yes. That is what it appears on the surface, Mr. Walker. And in the general case I would say that that is a correct statement.

But then I would add that these oddities start to come in that you find out that when they mandated the use of MTBE in Denver, Colorado, that they had difficulty starting the engines at 40 degrees or below, spark ignition. When they mandated ethanol in California, they are having trouble starting the cars at below 35 degrees. The methanol is difficult to start. You do not have those starting problems with the Stirling. I just simply do not have enough fleet data and enough statistical data to argue that point.

But I can say that is a truism. And I am just saying that for the money that has been invested by Congress and by the Government, I don't think that we should just chuck that alternative down the drain right now.

I just think that there are too many things coming down the pike—possible oil crisis, somebody mentioned that earlier; and the emissions and the alternative fuel issue—

that you would want to throw away your alternative, particularly while we are trying to commercialize it.

Mr. WALKER. Okay. Well, the only thing—I will be glad to yield to you in a second—the only thing I am saying to you is I do not see how we are chucking the technology. We bought the technology. We know where we are on it. My question is why spend another $2.5 million on it if we are not going to get a substantial upgrade out of the additional spending? We are certainly not chucking the technology. The technology is there. You all have developed it. We have spent $110 million. We have met our goals.

But is there a reason to go on spending the money simply to keep teams in place and that kind of thing?

Mr. NIGHTINGALE. Not at all, Mr. Walker. I think if I could simply try to address it in one statement, it would be that our entire charter in the program was to deal with liquid fuels. Now, you mentioned hydrogen as a fuel. Mr. Rohracbacher mentioned propane as a fuel. And I have mentioned in my testimony natural gas.

I am saying that we have not done any technology work on the Stirling engine for gaseous fuels, and I think that may be something of the future. The Germans have been playing with hydrogen as a fuel for automobiles.

I just feel that we have something here that we should not cut off working the fundamental technology while we try to commercialize on the other side. And I am not asking money for that aspect of it. I am only asking for the technology.

Mr. WALKER. I would be glad to yield to the gentleman from California.

Mr. ROHRABACHER. You are telling us that actually the engine has a benefit in terms of pollution and the emissions factors, but you are also telling us that there is a lack of performance.

Mr. NIGHTINGALE. Not in the Stirling, no. My statement was relative to the spark ignition.

Mr. ROHRABACHER. I thought we were talking about the Model T and upgrading the Model T so it is more powerful so that's how we get a little soup out of this thing.

Mr. VALENTINE. Mr. Nightingale, would you like to take back your reference Model Ts?

[Laughter.]

Mr. ROHRABACHER. I guess my question is if we start upgrading the performance, why are we to suspect that possible the emissions level won't be adversely affected, as usually happens when you're talking about higher-performance cars?

Mr. NIGHTINGALE. Without getting into a great deal of engineering—and I do have 12 years of gas turbine experience, so I can talk about that—the fundamental difference in the Stirling engine is the fact that it is an ambient burner. It is just like your oil burner in your basement. And we do not require any special changes to that combustion process to get the performance in the vehicle or the engine itself.

In the other, compression-type engines, spark ignition engines, you have to very carefully control your fuel-air mixture where you start to hear pinging or you start to lose some performance. The Stirling engine can work with a great deal more air and still accomplish its goal. So that we don't have to deal with that kind of problem.

Mr. WALKER. Thank you, Mr. Chairman.

Mr. VALENTINE. Thank you, sir.

I thank all of you very much.

I have a question, too. But I may write you a letter about that.

Thank you very much, all of you, for your appearance here today.

Next will be panel number three: Dr. James W. Patten, executive director of materials engineering, Cummins Engine Company, Inc., of Columbus, Indiana. Dr. Patten is accompanied by Dr. Carl T.J. Ahlers, vice president, technical planning.

Welcome. Your statement will appear in the record, Doctor. If you will summarize or otherwise proceed in any way that you think appropriate.

STATEMENT OF JAMES W. PATTEN EXECUTIVE DIRECTOR MATERIALS ENGINEERING CUMMINS ENGINE COMPANY, INC. ACCOMPANIED BY: CARL T.J. AHLERS VICE PRESIDENT TECHNICAL PLANNING

Dr. PATTEN. Thank you, Mr. Chairman, committee members, for inviting me to testify today. I will go through the testimony as I presented it to you.

I would certainly encourage the same sort of questions that were asked of the alternative-engine community.

First, let me tell you a little bit about who I am, Cummins, and our involvement with DOE. I have been with Cummins for about seven years. I joined Cummins with the objective of transferring technology to the diesel engine business from other advanced technology industries. I now have the responsibility for materials engineering and the manufacturing processes research and development activities.

I was at Battelle's Pacific Northwest Laboratories before Cummins, was there for about 13 years, and managed the original Hanford plutonium weapons group.

One of my other responsibilities at Battelle was the lead laboratory function for the DOE combustion zone durability program.

I am currently involved as an industry adviser to several of the DOE-NSF programs, including the advisory board for the Oak Ridge high-temperature materials lab.

But I am quite familiar with the internal workings of DOE and have been for many years.

I am a metallurgist and physicist by training, with a great deal of business exposure also.

Cummins is currently involved in two technology-driven joint ventures with Japanese companies that my group has led. So, some of the questions may pertain directly to things that we are involved in.

Cummins is a world leading company in manufacturing heavy-duty diesel engines and related system components. We are independent, and we sell our products to other companies who, in general, are trucking companies but who make their own engines. So, we are in competition with subdivisions of our customers, in many cases.

The bulk of our product is appropriate for heavy-duty truck use, although it goes up and down in horsepower from there. We make about 55 percent of heavy-duty truck engines in the United States today. And it varies up to—it has been as high as something over 60 percent in heavy-duty truck industries.

We also make over 40 percent of the heavy-duty turbochargers in the world through our subsidiary, Holset, and we sell those turbochargers to almost all the diesel engine manufacturers.

Our annual sales are well over $3 billion, and about a third of those sales go overseas. We manufacture around the world in several locations in the United States, but almost all of our engineering work is done in Columbus, Indiana.

Heavy-duty transportation in the United States is largely truck transportation. Our quality of life, our industrial competitiveness, and military security all depend heavily on the efficiency and dependability of heavy-duty truck transportation.

With the development of very fuel-efficient and durable diesel engines, almost all gasoline engines were displaced from the commercial freight transportation.

Continued development of heavy-duty diesels has resulted in more than a 25 percent improvement in fuel economy over the past ten years, and durability has been improved by a factor of two to five in terms of the time it takes to wear an engine out sufficiently to require a first major overhaul.

The interesting thing, at least to me as a technologist, is that the pace of heavy-duty diesel technology development is actually now accelerating. It hasn't flattened out at all. It seems as though that is based on accumulated knowledge base with which to understand the world that we are working in. So, it is very easily demonstrated that there is a great deal of potential yet untapped.

The technology is becoming very attractive for application to the light-truck sector, which is really heavy-duty pickups, above the 8600 GVW breakoff, which is the current breakoff for heavy-duty pickup trucks.

For many years, heavy-duty diesel companies like ourselves, universities, Government laboratories, military organizations, and other interested parties have continually tried to develop alternative power plant concepts and evaluate and continue to evaluate several concepts every year. But as yet, no technology has been identified with a competitive thermodynamic foundation and an acceptable match for existing materials and manufacturing technology, given the requirements for operating cost and performance in U.S. heavy-duty truck transportation.

Furthermore, as emission control technologies are developed and implemented in response to the '91 and '94 diesel emissions standards, the differential in environmental input between diesels and our alternate fuel engines is being reduced significantly.

In terms of research needs, heavy-duty truck transportation in the United States has needs centered around: reductions in operating costs; reductions in fuel consumption, which really impact both operating cost and national dependence on foreign oil—actually, the fuel consumption costs are the largest element in operating costs for many truckers; minimization of impact on our environment; and the defense of the U.S. infrastructure; and the very attractive North American markets against foreign competition.

These needs really break down into specific needs for: reduced fuel consumption; reduced emissions; reduced equipment first cost; increased reliability and durability and improvements in the supporting technologies such as design, materials, and manufacturing; and needs for early warning concerning the technical feasibility of competing technologies such as we heard about today.

The DOE's heavy-duty transport program supports many of these needs either directly or indirectly. The charter has been to pursue long-range higher-risk technology that will result in reductions in fuel consumption.

More recently, really since about last year, all fuel consumption reduction research is being examined critically for potential to reduce harmful emissions. And that is entirely appropriate.

The automotive projects supported by the DOE automotive transportation program have been heavily weighted towards exploration of new engine alternatives for automobiles, particularly small, high-temperature gas turbines and Stirling's, as the previous testimony dealt with.

These projects have been the premier efforts of their kind in the world and have given and are giving the heavy- duty diesel community a very good assessment of the competitive threat posed by these technologies for heavy- truck transportation.

Most diesel makers have had similar internal programs, and the are reviewed regularly to assess the technology's progress. The DOE programs clearly support these needs.

The heavy-duty transport projects focused directly on diesel technology have been well linked with specific fuel economy needs and opportunities and can be clearly associated with reductions in heat rejection and fuel consumption over the last few years.

Although the original adiabatic engine concept was found to be an oversimplified approach and has not yielded directly the expected efficiency improvements, the analytical tools and the low heat rejection understanding that have been developed on these projects have produced more efficient and durable engines in production today.

Through these heavy-duty transport diesel technology projects, we have recognized further opportunities to exploit the properties of advanced materials, including ceramics but not restricted to ceramics, to reduce fuel consumption and emissions, reduce cost, and increase durability.

In addition, the heavy-duty transport diesel technology management has been very effective in monitoring new technology worldwide and challenging the thinking in the U.S. diesel community to reexamine past analytical findings and study new concepts.

Technical competition between U.S. diesel companies has also been encouraged actively, as you have seen in the gas turbine automotive program. This leadership has been essential to the success of the program. Although small, the diesel program is known worldwide and recognized as a leader in technology development.

The heavy-duty transport projects focused on alternate fuels have been very small. They have only been able to serve as a window to technology and an expression of interest on the part of DOE.

There is a great untapped potential for engine systems research directed to the use of methanol and natural gas, with the promise of both reducing consumption of oil and reducing emissions.

In summary, the DOE heavy-duty transport program is effectively within its charter and well linked to the U.S. heavy-duty transport infrastructure. Individual projects are focused on important goals and attractive project opportunities far exceed available funding. As is true in our own company, that is a sure sign of a healthy program and sound management.

Attractive opportunities for new focus in the future includes development of heavy-duty diesel technology for light-truck applications, development of heavy-duty engine systems for methanol and natural gas, development of engine subsystems such as turbochargers and fuel systems in particular for better efficiency over the entire operating and duty cycle, and continued materials development to extend the possibilities for new designs.

Thank you, Mr. Chairman.

Mr. VALENTINE. Thank you, sir.

How would you, Dr. Patten, how will the diesel industry, in your opinion, meet the '91 and '94 emissions standards for oxides of nitrogen and particulates? And will alternate fuels be needed?

Dr. PATTEN. Mr. Ahlers will answer questions related to emissions and where we stand as to meeting the standards.

Mr. AHLERS. Sir, as you know, there are two requirements for 1991: the urban bus requirement and also the heavy-duty truck requirement. The heavy-duty truck requirement, we are well down the road in our development programs, to offer a full line of products which will comply with 1991 truck standards.

We are also developing engines to meet the 1991 urban bus standards. The engines we are developing are alternate fuel engines. Those engines are fueled either with methanol, and the other choice is compressed natural gas. There are two parallel development programs aimed at alternate fuel products for 1991.

For 1994, we have a very active research program aimed at certifying our products by those standards. The status of that research program is that we have not yet demonstrated those emissions levels in the laboratory, but we are confident that through our research work we will meet those goals.

Mr. VALENTINE. How do you view the various cuts in DOE's heavy-duty transport program such as the liquid high-temperature lubricant development?

Dr. PATTEN. Sir, let me give you a somewhat lengthy answer to that question. The programs that are in the plan as it is structured today include work in particular on tribology and the insular components activity.

If you stretch one of the state-of-the-art diesels today to higher output for better fuel economy or what have you, the pieces that break are the in-cylinder components. That is the weak point of the engine. So, it is clear, as was described to you earlier, the in-cylinder components activity is a higher priority activity.

On the other hand, a very substantial portion of particulate emissions that are generated from a diesel engine today come from consumption of the lubricant oil. As you improve the combustion process further and further toward the '94 standards, you find yourself facing a situation where the oil consumption in the very best engines in the world today represents all the particulate emissions before degenerating, even burning no fuel, in the '94 scenario, with some slack for measurement variability and production variability.

So, I think in terms of meeting particulate standards, advanced lubricants that incorporate both the synthetic base stock doesn't contribute to the particulate and an excellent additive package that doesn't contribute to the particulate is a really important piece of work.

It is also true that we are concerned about how well engines last, whether or not they degrade in their emissions generation characteristics or their fuel consumption or performance characteristics over a period of time.

That is very tightly linked to developments in advanced lubricant technology. So, Cummins does not like to put themselves in a position of asking for additional funding. I think that is the appropriate role of this committee is deciding how much money goes where and so forth.

I can tell you that in the case of the program you mentioned, that work is essential. It will go on with or without DOE funding.

DOE funding has acted so far as a nucleus to excite the petroleum industry to do things more quickly than they otherwise would, to marshal some resources and get people talking and get them working that otherwise would not.

I think that is an appropriate role for a group like DOE to play.

Mr. VALENTINE. Thank you, sir.

Mr. Lewis?

Mr. LEWIS. I have no questions, Mr. Chairman.

Mr. VALENTINE. Mr. Rohrabacher?

Mr. ROHRABACHER. Mr. Patten, first of all, how long have you been under a subsidized situation? How long has the Government been giving you money for research?

Dr. PATTEN. I have personally been working on Government contract work for some portion of my activities for probably 20 years.

Mr. ROHRABACHER. No; I mean this company.

Dr. PATTEN. At this company, much of the work that we are doing today, that you talked to the gas turbine community about, is not subsidized at all by Government programs.

In terms of some of the work, the nickel aluminide work is licensed from Oak Ridge. That work, we are net funders of DOE. You know, it's an unusual situation.

Mr. ROHRABACHER. You are asking for some money here, are you not?

Dr. PATTEN. Sure. Stay with me a second. For work like the plasma spray insulated coating work, the current heavy-duty transport program, that is a relatively new program, a couple of years old. We have already demonstrated some capabilities to run things in the production type of engines.

We have cost-shared, if you really count everything on paper when we make the proposal, it is 25 percent or 30 percent or whatever. We provide the bulk of the funding.

In the case of the ceramic wear components that we put into production last week, the first example of structural ceramics in a heavy-duty diesel engine ever any place in the world, that is work that some of the DOE work supported indirectly. But all of the funding was internal.

So, it is a case where there are opportunities for some real research help there.

Mr. ROHRABACHER. What I am saying is your company has been helped along for how long by grants from DOE?

Dr. PATTEN. I would say the first project of any kind from DOE has probably been—you will have to help me out—maybe 10 or 12 years ago, something like that. 1978.

Mr. ROHRABACHER. It seems like a lot of things started in 1978.

Dr. PATTEN. I would point out, though, that virtually all of those programs have been shorter-term programs where we each an end point and some milestones have been achieved, and we have gone.

Mr. ROHRABACHER. Absolutely fair. I am not suggesting anything else. And during that time period, however, what we are talking about since 1978, you say that there has been a 25 percent increase in efficiency in what diesel engines can do?

Dr. PATTEN. That is actually a conservative estimate.

Mr. ROHRABACHER. And that is the direct result of your activities and the research that came out?

Dr. PATTEN. The DOE work has certainly helped that.

Mr. ROHRABACHER. And there has been a major reduction in emissions at the same time?

Dr. PATTEN. That is correct, sir.

I didn't bring the graphics, but I would be happy to provide them to the committee as to what actually has happened to the performance of our engines in terms of emissions and so forth over that period of time, either particulate emissions, NOX, fuel consumption, or all three.

Mr. ROHRABACHER. So, due to a lot of the research that we have helped finance and your company has been involved in, how much money for some 25 percent efficiency? That is quite a lot of savings to the American people, isn't it?

Dr. PATTEN. I would think so, yes. It certainly helps.

Mr. ROHRABACHER. What kind of magnitude are we talking about? Are we talking about hundreds of millions of dollars?

Dr. PATTEN. Certainly we haven't done the analysis.

Mr. ROHRABACHER. Well, maybe you can think about that.

Dr. PATTEN. Yes.

Mr. ROHRABACHER. It seems like the type of information that the American people would want to know about.

You talked about advanced lubricants. You heard my question earlier about diesel trucks with the big black stuff coming out of the smokestack. Well, that is part of the lubricants.

Dr. PATTEN. Yes. Part of it may very well be antiquated engines and part of it may be engines that are not set up properly.

Mr. ROHRABACHER. Will the advanced lubricants that you have talked about help solve that problem?

Dr. PATTEN. Yes, sir.

Mr. ROHRABACHER. Can we expect in the future that we will be seeing some? I mean this is pretty impressive progress, as far as I am concerned. You tell us that you have had a 25 percent efficiency increase in diesel engines plus major progress in terms of emissions. That is very impressive.

But are we going to face a situation where we are going to ride along the highway someday and not see all this big black junk coming out of these trucks?

Dr. PATTEN. I think if you follow the Cummins L-10 and MT Powered Trucks today, of modern production, you wouldn't see big clouds of black stuff.

Mr. ROHRABACHER. So, this is going to be a thing of the past. Right?

Mr. AHLERS. I would just like to add to that. The black smoke that you see is composed of many different products, some of which is the particulate emissions which first came under Federal regulations in 1988. And engines prior to that weren't subject to that standard. So, engines prior to that might have a higher emissions level.

That standard for 1991 is 0.25, something like a 60 percent reduction, and then for 1994, 0.1, which is about an 80 percent reduction.

Mr. ROHRABACHER. Do you think those standards can be met? Do you want to think about that?

Mr. AHLERS. I stated before, the 1991 standard we are confident we can meet it when we are using low-sulfur fuel. And the 1994 standard, I would say we are still in the research stage.

Mr. ROHRABACHER. You talk about meeting these standards with methanol—or methane, excuse me.

Mr. AHLERS. Yes. I talked about meeting the 1991 urban bus standard with methane and methanol.

Mr. ROHRABACHER. And compressed natural gas.

Mr. AHLERS. Yes.

Mr. ROHRABACHER. Well, let me just ask you a general question. Do you see the diesel engine as being something that we are going to have 50 years from now? Is it still going to play a major role in the United States? Is this an engine of the past or an engine of the future?

Dr. PATTEN. We absolutely do not agree with Mr. Helms. Today you can buy a state-of-the-art diesel engine from either ourselves or a small number of other high-technology makers that approaches 50 percent thermal efficiency. You can't find another system any place except possibly in giant stationary power plants with that kind of thermal efficiency.

We are on a steep growth curve. We are still improving efficiency very rapidly. We are just beginning to understand how to make engines very efficient over the entire operating duty cycle.

To us, our thermodynamic analysis tells us that fuel efficiency in engines for transportation is really determined by peak pressure in the combustion chamber and by losses like you get with blow-by around piston rings or like you get with gases blowing past the tips of the gas turbines.

To us that says that the advantages of turbine machinery belong in front of and behind the combustion chamber in turbochargers and that sort of thing. But the most efficient combustion chamber will be a closed combustion chamber with very high peak cylinder pressures, some sort of a reciprocating—it doesn't say it will be a diesel, but it does say it will be a closed chamber high-pressure combustion system.

So, this is our business. This is 55 percent of the transportation in the United States. You would hear the exact same story from Caterpillar, who is maybe 25 percent of that same business. We have both had gas turbine programs. We have evaluated the Stirling and so forth. And we have our eye on technology, as Mr. Helms said, as GM does. But we see the future being high-pressure reciprocators.

The other engine programs have a long, long way to go, even for their experimental engines, before they even get to where we are with commercial engine systems.

Mr. Rohrabacher. Do you see any future in terms of large engines, heavy engines, for propane in terms of large engines, heavy engines?

Mr. Ahlers. We have also evaluated propane as a fuel. It isn't one of our primary fuels right now. Propane runs much the same as methane does, with a slightly different fuel injection system but with much the same characteristics.

I just would like to add one comment as far as the future of the diesel and it is relative to the new pollutant that is on the horizon that people are talking about now, and it is related to the global warming.

It is felt that global warming is somehow associated with carbon dioxide emissions, and carbon dioxide emissions are emissions which run exactly parallel to efficiency. That is, the higher the efficiency of the engine, the lower the carbon dioxide. So, everything that Dr. Patten said about the highest thermal efficiency in diesel engines also means the lowest CO2 emissions.

That is the under rated pollutant now, and that is the pollutant we will probably be talking about by next year.

Mr. Rohrabacher. That is all.

Dr. Patten. One parting comment, I guess. Although we are a very strong believer in the diesel camp and by far the largest effort in our shop is with the diesel, I think it would be ill-advised not to keep an eye on the other technologies and keep an active, aggressive program going there, because if you look at the state of understanding of Cummins ten years ago and compare that with the state of understanding today, the difference is absolutely striking. I think that we don't know far exceeds what we do know.

So, a fundamental inquisitive viewpoint, I think, is going to be valuable to all of us within the next few years as we become more and more concerned about the environment.

Mr. Valentine. Thank you.

I think Mr. Lewis had one question.

Mr. Lewis. Thank you, Mr. Chairman.

Dr. Patten, you stated you were using some ceramic parts in your engines today?

Dr. Patten. As of one week ago.

Mr. Lewis. As of one week ago. Are you at liberty to say what type of parts they are?

Dr. Patten. Sure. These are wear components made of silicon nitride. They are part of the fuel injection system. So, they are subjected to stresses in excess of 100,000 pounds per square inch. Every time there is a fire in the diesel cylinder, they transmit force from the fuel injector to squirt the fuel in the combustion chamber.

The key attribute of the ceramics for us is wear resistance. As we strive to deal with more and more stringent emissions regulations and more stringent expectations for fuel economy from our customers' point of view, we have found that very high-pressure fuel injection is a key tool to deal with these changing conditions.

As you up the injection pressure and you try to shape the time pressure history with which you inject fuel into the combustion chamber, you really increase the loads on the mechanism that causes the fuel injection pressure. That generates wear and changes in setting and degradation and system performance over a period of time.

We discovered that with conventional lubricant systems that ceramic materials we have identified have on the order of five times better wear resistance than the very best metallic systems that we are aware of. So, that is what is driving this particular application.

Mr. LEWIS. I see. Were these parts developed under the Government program?

Dr. PATTEN. No, they were not. They were developed as part of a joint venture between ourselves and the Japanese company, Toshiba.

Mr. LEWIS. You mentioned—are these parts plasma- sprayed as well?

Dr. PATTEN. No, they are monolithic. They are a freestanding piece of ceramic. Having said that, there is a wear and tribology program DOE is funding around both ceramic coatings and mechanisms of wear that will help us understand the phenomenological aspects of what is going on.

We found a system that works. We have some theories about why the system works. But the fundamental understanding is still lacking. We are hoping that some of the DOE programs will help elucidate the mechanisms so that they can be clearly understood, the problems solved and transferred to other applications.

Mr. LEWIS. It is interesting that the ceramic parts have the closest tolerances as well.

Dr. PATTEN. That's right.

Mr. LEWIS. Thank you, Mr. Chairman.

Mr. VALENTINE. Thank you, gentlemen, very much.

Panel four, the last witness, is Dr. Gene G. Mannella, director of the Washington office of the Electric Power Research Institute.

Welcome, sir. As I have said to the other witnesses who have testified here, your testimony will appear in the record in toto, as you have submitted it to us. Feel free to summarize or otherwise proceed in any way which you deem appropriate. We are glad to have you here, sir.

STATEMENT OF DR. GENE G. MANNELLA DIRECTOR, WASHINGTON OFFICE ELECTRIC POWER RESEARCH INSTITUTE

Dr. MANNELLA. Thank you very much, Mr. Chairman.

We certainly appreciate the opportunity to appear before you today to tell you a little bit about EPRI's electric vehicle program and comment on the FY 1990 budget request for electric vehicles and related activities at DOE.

As you know, Mr. Chairman, EPRI, which is based in Palo Alto, California—and let me say parenthetically we can't think of a better assignment for Tom Campbell than HSS&T—was established by the electric utility industry in 1972 to conduct a broad research and development program on behalf of the utility industry and its customers. Our mission is to develop technology for electric power production delivery and use.

Specifically, with regard to electric vehicles, we believe very strongly that EVs could become a commercial reality within the next few years. In fact, we think that there is the possibility that a sufficient number of EVs could be in use by the year 2000 to provide the well- recognized benefits to society in the area of air quality improvements, particularly in urban areas, and reduction of oil imports.

We are making progress, but it is slow partly because the efforts nationally are resource-limited. EPRI has been spending about $3 million a year on EVs. DOE's budget has been up to this year about $13 million a year. Electric utilities themselves, apart from EPRI, have been budgeting about $4 million or $5 million a year, so that nationally only about $20 million is being spent per year on this technology that can have such enormous benefits.

With such limited dollars, careful planning and coordination is a must. And as we reported last year to this subcommittee, we have been part of a coordinated program that has been in place since 1986 and includes the Department of Energy, the Electric Vehicle Development Corporation, and the Electric Power Research Institute, each of these three partners bringing something specific to the table.

EVDC, which is a nonprofit organization supported by over 40 percent of the U.S. electric utility industry, is charged with developing the infrastructure necessary to commercialize EVs.

EPRI concentrates on the design and development of reliable, marketable vehicles.

And DOE has been supporting the longer-range, higher- risk activities needed to provide the additional technology.

This program has been in effect for over two years. And I believe it is recognized as an outstanding example of Government-private sector coordination and cooperation.

Because of the progress that we have seen—and I have attributed it to all three parties over the past several years—EPRI has recently doubled its budget for electric vehicles. Again, as we reported last year, our efforts focused on the urban delivery van.

Fleet vans, we think, offer a very attractive initial market for electric vehicle introduction for three reasons, the first of which is that many vans in an urban environment are used for short trips and return to a central facility each night. This simplifies the infrastructure requirements to maintain such a fleet.

Secondly, electric utilities themselves use many vans. Thus, they could assist in the initial market penetration for fleet vans.

Finally, clean fleet vans operate primarily in urban settings where air pollution problems are most severe and where they could provide the most immediate relief.

In terms of progress, I am very happy to report that within the past year we have added 31 GM Griffin vans, which were imported from the United Kingdom on test. And they have performed very well, logging over half a million miles with very attractive results.

In November of last year, a concept vehicle, the G-van, which is based upon GM's Vandura, was produced. EPRI has commissioned a significant effort to complete the production, engineering, and certification of this van to meet the Federal motor vehicle safety standards, which we expect to be completed in 1989.

If we are successful, G-vans could be marketed nationally by 1990. Since the range of electric vehicles primarily depends upon the battery, we are also happy to report progress in the use of nickel-iron batteries by the Chrysler Corporation in an effort called the TEVAN. This could lead to a vehicle with a range of 120 miles.

A concept vehicle has been produced and performance tests will be conducted in 1989.

Finally, the next-generation propulsion system, which we think is extremely important to extend the range and the marketability of electric vehicles, a range of perhaps up to 150 miles is being developed at Ford under DOE sponsorship, a program that is called the ETX-II.

This leads us to the issue of the FY '90 budget request. And I would like to say that we certainly are cognizant of the fact that the budget deficit is a major problem and we support the efforts of the Congress and the Administration to address this problem. We would like to think of ourselves as good corporate citizens.

However, we are concerned with the fact that the Department of Energy's FY '90 request for electric vehicle R&D is 65 percent below that for FY '89. We feel this can only send the wrong message to other potential participants in the commercialization process.

While the DOE EV efforts are modest, they are nevertheless important to our coordinated efforts. For example, we are of the opinion that the nickel-iron battery is perhaps the only other battery besides lead-acid that has a prototype that has shown required lifetimes on vehicle tests that could be utilized in commercial vehicles.

We are relying on DOE to complete the necessary nickel- iron battery R&D.

The ETX-II program I mentioned is very important for the development of an AC-drive train, lighter and more efficient, for a vehicle with an extended range of 150 miles and up in the mid-'1990s.

Again, we are relying upon DOE to complete that program. And given the importance of our higher-performance batteries, R&D should continue not only on the nickel-iron battery but on one or two others which we would identify as not only the lithium metal sulfide, but advanced lead-acid batteries as well.

We are perhaps taking for granted the state-of-the-art lead-acid technology and the role it would play in the initial introductory vehicle. That is the crucial step in the commercialization of electric vehicles.

Finally, this year's DOE request would reduce support for the site operators user task force, which we feel is vital, which has garnered much useful data. We hope that during this calendar year, the electric vehicle commercialization infrastructure, led by EVDC and supported by EPRI, will continue to the point where these user evaluations can begin to transition over to the private sector.

But the figure that is asked for by DOE this year we feel would bring about a premature reduction of this effort.

Mr. Chairman, let me summarize by saying that we feel that electric vehicles are on the verge of the introduction of the initial vehicle with a limited range of a 60-mile fleet van. We think it is reasonable to expect improvements in this type of vehicle to the 100-mile range by '92 and the 150-mile range by about 1995.

The infrastructure is being established by the Electric Vehicle Development Corporation and electric utilities. EPRI is completing the production, design, and engineering of advanced vans such as the TEVAN.

We are relying upon DOE to continue the R&D necessary to make the drive train as well as the high-performance batteries.

We feel strongly that because electric vehicles address clean air, energy conservation and energy security goals, the program must be maintained at at least the FY '89 levels. We back up our belief with an increase in our budget of 100 percent. DOE should at least remain at the '89 levels.

That concludes my remarks, Mr. Chairman. I would be happy to answer any questions you might have at this time.

[The prepared statement of Mr. Arnold P. Fickett, as presented by Mr. Mannella follows.]

STATEMENT OF

ARNOLD P. FICKETT

VICE PRESIDENT, CUSTOMER SYSTEMS DIVISION

ELECTRIC POWER RESEARCH INSTITUTE

PRESENTED BY

GENE G. MANNELLA

DIRECTOR, WASHINGTON OFFICE

ELECTRIC POWER RESEARCH INSTITUTE

BEFORE THE

SUBCOMMITTE ON TRANSPORTATION, AVIATION AND MATERIALS

COMMITTEE ON SCIENCE, SPACE AND TECHNOLOGY

U.S. HOUSE OF REPRESENTATIVES

MARCH 8, 1989

Mr. Chairman, Members of the Subcommittee:

I am Gene Mannella, Director of the Electric Power Research Institute's (EPRI) Washington Office. I am pleased to appear before you and present this statement of Arnold Fickett, Vice President of EPRI's Customer Systems Division. Mr. Fickett's statement relates to the Department of Energy's (DOE) Transportation Program and the FY 1990 budget request for electric vehicles and related activities.

The Electric Power Research Institute was established by the electric utility industry in 1972 to conduct a broad research and development program on behalf of the electric utility industry and its rate payers. EPRI's mission is to develop new and improved technologies for electric power production, delivery and use, and to help accelerate the commercial availability of these technologies.

EPRI and its member utilities believe strongly that electric vehicles could become a commercial reality within the next few years. And, if provided the necessary support to further advance the technology and reduce the cost, we believe that a sufficient number of electric vehicles could be in use by the year 2000 to provide significant societal benefits, principally through the improvement of air quality in our urban areas, and the reduction of oil imports. There are over 160 million registered vehicles in the United States today. For every 1% of that fleet replaced by electric vehicles, we could reduce urban emissions by 160,000 tons per year and save 60,000 barrels of oil per day, figures which are extremely significant in terms of our efforts to conserve energy, protect the environment and achieve energy security.

Despite this potential, progress toward these goals has been slow, primarily due to the lack of resources committed to this effort. Prior to this year, EPRI's budget for EV's was approximately $3 million/year; with DOE was spending about $13 million/year on R&D in support of electric and hybrid vehicles. Electric utilities, both individually and through the Electric Vehicle Development Corporation (EVDC), are spending an additional $4-5 million/year. Thus, nationally, only $20 million/year is being spent on a technology that can have enormous benefits to society.

Approximately one year ago, before this Subcommittee, we described the coordinated program that was put in place in 1986 by the three principal funding organizations--DOE, EVDC, and EPRI--and how that collaborative effort had been very effective in managing and coordinating our limited resources. That program was premised on the recognition that each of the principals had a primary role to play. EVDC, which is a non-profit organization supported by over 40% of the U.S. electric utility industry, emphasizes the infrastructure necessary to market, distribute and service electric vehicles. EPRI concentrates on the design and development of reliable, marketable electric vehicles. DOE supports the longer range, higher risk R&D activities needed to provide for an evolving technology base. This program has been in effect for over two years now and is recognized as an outstanding example of Government/private sector cooperation to allow better use of scarce resources in meeting societally important goals.

As a result of this coordinated program, and reinforced by the positive signals that this Subcommittee provided last year, EPRI has recently doubled its budget for electric vehicles. We are now engaged in an aggressive and high risk drive to have a marketable vehicle available in 1990. A reduction in the Department of Energy's budget at this time would undermine our efforts and the efforts of the other stakeholders and send the wrong signal to other potential players in EV commercialization. We are depending on DOE to develop the advanced technologies that will be needed if electric vehicles are to initially penetrate and then capture a growing share of the market.

As we discussed last year, the present status of U.S. electric vehicle activity continues to be extremely promising. The focus of this activity, in the near term, is the fleet van. Fleet vans offer a unique niche market for electric vehicle introduction for three reasons:

- Many fleet vans are used for short trips and return to a central facility every night. (For instance, 600,000 vans operate less than 60 miles each day; a service requirement now within the capability of the technology). This reduces infrastructure requirements to a minimum and allows economies of scale in providing service and maintenance.
- Electric utilities use many vans themselves; plus they have a desire to increase their off-peak loads. Thus, electric vans offer a unique opportunity for utilities to benefit in two ways--improve the operation of their van fleets, and improve load factors.
- Fleet vans operate primarily in urban settings where air pollution problems are most serve. Thus, electric vehicles can immediately help where the environmental need is the greatest. Hopefully, in some instances this can be translated into some form of financial credit to help the initial introduction.

Specific activities that support the fleet van program include the following accomplishments:

- Thirty-one GM Griffon vans, imported from the United Kingdom, have been tested by eight utilities and, to date, have provided 500,000 miles of very reliable service, as well as invaluable data and operating experience.

- In November 1987, a proof-of-concept domestic van (the G-Van), based upon GM's Vandura, was produced. Performance tests of this van met or exceeded expectations. As a result, EPRI commissioned a multimillion dollar effort to complete production engineering and certification to Federal Motor Vehicle Safety Standards (FMVSS). This effort is expected to be completed in 1989. In the meantime, EVDC and the electric utility industry are marshaling resources to establish a distribution infrastructure. If we are successful, G-Vans could be marketed nationally by 1990.

- The range of an electric vehicle is primarily dependent upon the energy density of the battery; that is, the amount of energy per pound that can be stored (and carried on board the vehicle). To extend the range--and the market--Chrysler has a development underway involving the use of the nickel-iron battery in minivans. This effort, the TEVan, could lead to a vehicle with a range of 120 miles. A concept vehicle has been produced and performance tests will be conducted throughout 1989. Before this vehicle can become a commercial reality, manufacturing facilities will need to be put in place for both the nickel-iron battery and for the vehicle.

- A next generation propulsion system is being developed by Ford under DOE sponsorship. This ETX-II Program has pioneered the use of ac drive and more energetic batteries. This combination could lead to a vehicle with a range of 150-200 miles.

We are concerned with the Department's FY 1990 request for an Electric and Hybrid Vehicle R&D budget that is 65% below FY 1989 levels. We are nearing the threshold of a commercial electric vehicle technology. Now is the time to accelerate our national efforts, not reduce them. We need to provide technological advances that will capture and expand the market opportunities.

We also need to send a message to other potential participants in the commercialization process that technological developments will continue and that electric vehicles are indeed a viable option. This message needs to be clearly stated for the automotive industry which is not yet an enthusiastic participant in the electric vehicle commercialization process.

While the present (FY 1989) DOE electric vehicle efforts are modest, these are nevertheless important to our coordinated efforts. Furthermore, there are certain critical activities that have been reduced or eliminated in DOE's FY 1990 request and whose restoration is crucial to the orderly development of a viable electric vehicle technology. These include the following:

- The nickel-iron battery is the only battery other than lead-acid that, as a prototype, has shown required lifetimes in vehicle tests. Once fully developed, this battery would offer a range extension of 50-100% over lead-acid. We are relying upon DOE to complete the necessary nickel-iron battery R&D. It is critical that these efforts, particularly those related to the new fiber electrodes, be continued or even expedited.

- The ETX-II Program is important to the development of an ac drive train and its integration with advanced batteries in an electric vehicle. This activity will provide the advances necessary to make possible vehicles with a range of over 150 miles by the year 1995.

- Given the importance of higher performance batteries to the future potential of the electric vehicles, R&D should continue on not only on nickel-iron, but also on advanced lead-acid, lithium-sulfide, zinc-bromine and sodium-sulfur batteries. The DOE request marginally provides for the latter three. However, it does not provide support for advancing lead-acid batteries.

- The DOE request would also reduce support for the Site Operator's User Task Force. This Program has been vital in developing fleet data necessary to determine the viability of new technologies and define R&D needs. We hope that during 1989, an electric vehicle commercialization infrastructure will be established by the private sector and, at that time, responsibility for those "user evaluations" can begin to shift from DOE to the private sector. DOE's premature reduction of this effort would be unfortunate.

In summary, Mr. Chairman, let me conclude by making the following observations:

- The electric vehicle community is on the verge of the commercial introduction of limited (60 mile) range fleet van. It is reasonable to expect that commercial vehicles with over 100 mile range can be available by 1992, with a 150 mile electric vehicle available by 1995. Each of these plateaus of performance potentially adds significant numbers of electric vehicles to the Nation's fleet with commensurate energy conservation and environmental benefits.

- EVDC and the electric utilities are establishing an infrastructure to market, distribute, and service these vehicles.

- EPRI is committed to complete the production, design, and engineering of these vehicles, as well as support the development and production of the advanced components (i.e., batteries).

- We are relying on DOE to continue the R&D necessary to provide the technological advances to the battery and drive train necessary to expand the market and assure U.S. leadership among the international community.

- The electric vehicle development community is resource limited. In addition to the specific areas described above, where the reductions in DOE's FY 1990 request are critical, there are also many opportunities where additional funds could be responsibly utilized. For instance, any advanced battery will require considerable resources to move from the laboratory to mass production at costs that will justify their use in commercial vehicles. Although the private sector understands that they have to put the investment in place to achieve commercialization, the societal benefits of electric vehicles argue for Government assistance and incentives to stimulate the commercialization process.

For a variety of reasons, encompassing clear air, energy conservation, and energy security goals, the electric vehicle program must be maintained at least at FY 1989 levels. Further, we urge you to consider additional roles for DOE which could expedite the commercialization of electric vehicles. The electric utility industry is committed to making this endeavor successful, and as proof of this this, we have increased our level of participation. You can help by continuing to provide the proper signals and by assuring continuity of the complementary Federal role in this promising government-industry collaborative program to introduce an attractive new technology.

Mr. Chairman and Members of the Subcommittee, I thank you for this opportunity to describe our program and to present our thoughts on the DOE electric vehicle program. I would be happy to answer any questions you might have at this time.

Mr. **Valentine**. Thank you, Doctor.

What would be the approximate cost or price of one of these vans when they go on the market?

Dr. **Mannella**. The vans that we have contracted for, the G-vans, a number that varies between 30 and 100, depending on how many applicants we get to work with these vans, is probably somewhere in the neighborhood of $60,000 or $70,000 per copy, which certainly sounds excessive compared to the price of a conventionally powered van, but for a limited production run introductory vehicle it is not unusual at all. But that is the price range.

Mr. **Valentine**. What would be the approximate size of the battery or batteries and the cost of the batteries?

Dr. **Mannella**. I don't have a separate price for the battery. The van itself would have a payload of about 1800 pounds. It could carry eight passengers at a top speed of 52 miles per hour and, as I mentioned, a range of 60 miles.

The next vehicle in line, the TEVAN, the one we hope will have a range in urban driving of 120 miles per hour, the one which we hope will also have a nickel-iron battery, although we will be testing some advanced lead batteries, will have a payload of 1200 pounds. The TEVAN is slightly smaller than the G-van.

Mr. **Valentine**. Are you talking about a battery that is two feet square?

Dr. **Mannella**. Oh, battery packs. Typically—let me see if I can make a generalized statement. If you used as an envelope a battery pack for the electric vehicle, there might be 36 of those packages, 32 of those packages, something like that.

They are usually arranged in a tray-type configuration. Very frequently they are fitted into the underside of the van structure. So, they really don't intrude in the passenger compartment per se in most of the designs that I have seen.

Mr. **Valentine**. Do you believe that the inching up, so- called, in the performance of lead-acid electric vehicle batteries warrants our continued support for their development?

Dr. **Mannella**. Indeed I do, Mr. Chairman, because I think it is extremely important that the first articles that get introduced have as much reliability, ruggedness, and durability as we can build into them. And as I mentioned in my brief remarks here, I think there has been a little bit of a tendency to overlook the role that an improved, ruggedized, higher-energy density lead-acid battery could play.

I am personally of the opinion that an advanced lead- acid battery could power a van that would suffice for a very large number of vehicles, particularly in urban areas like L.A., Denver, and Washington.

Mr. **Valentine**. In your opinion, should both Ford and the Eaton propulsion systems work be continued for FY '90? And the second part of my question is what follow-up work should be done in this area as we complete these programs, in your opinion?

Dr. **Mannella**. We are particularly impressed with the potential of the Ford ETX, the integrated-drive motor transaxial AC assembly. The AC type of drive has some attractions in terms of mass and cost which are vital, in our opinion, to any successful introduction of fleet vans, certainly.

So, we would support that very much.

The Eaton work, I have to confess I am not as familiar with. And we don't see quite the same role for it in our evolving program as we do for the ETX-II.

Mr. **Valentine**. Mr. Lewis?

Mr. **Lewis**. I have a couple of questions, Mr. Chairman, for Mr. Manella.

You are specifically looking at stepping up from the 60- to 150-mile range by 1995.

Dr. **Mannella**. That is the goal, yes, sir.

Mr. **Lewis**. I guess most people today look at the electric car as nothing more than a golf cart. And a lot of them have had bad experiences with those.

What would your general vision be of an electric car? What would its general use be? A second car, just for short drives, going to the grocery store?

It just seems to me that unless you are going to be able to go 300 miles and drive at least 60 miles an hour, you are really not going to have a market for this vehicle.

Dr. **Mannella**. That is a very profound question that you are asking. Let me say that all other things being equal, if you combine all of the gasoline that you need at 90 cents a gallon and there are no other constraints on how do you use it in terms of air quality or what have you, it is extremely difficult to think of anything that could compete with a IC-powered liquid-fueled vehicle. It is an extremely highly developed development. Hundreds of thousands of man- years of development on that project.

It is only when one begins to think in terms of some of the things we mentioned earlier here today, about urban pollution, about global warming, about oxides of nitrogen, when one thinks of the possibility, as regrettable as it may be, of another oil cutoff from the Mideast, and when one looks in particular at the technical responses that we would have available to address some of these questions in urban areas, that the idea of a fleet van or a commuter car powered by electricity I think begins to come into its own.

It is that kind of milieu in which we would have to operate. I personally don't believe—and I have worked on experimental vehicles and electric vehicles and what not when I was in the public service for 20 years—I personally don't believe we are ever going to see, at least in my lifetime an electric vehicle that can identically duplicate the range and performance of an IC-powered vehicle at the same cost.

Mr. **Lewis**. I guess you're right.

What sort of—I guess I am not familiar enough with the battery pack—but what sort of situation are you looking at? We have enough problems just with the standard 12-volt battery now where they blow up in people's faces and things like this. What kind of research are you doing? I envision this thing as pulling up into your garage, plugging in, charging up, that sort of thing.

Dr. **Mannella**. Exactly.

Mr. **Lewis**. What sort of research are you doing to make sure that we don't have the accidents with these larger battery packs? The average homeowner today has enough problems just getting their car checked out of the garage for $300. How about with the electric car, what are we going to do with that?

Dr. MANNELLA. Let me point out that the vehicle we are doing to do most of our learning and development is a fleet van, and this was very consciously chosen because fleets are maintained by mechanics. They have a regular schedule and what have you.

However, your question certainly has relevance for growth beyond the application of fleet vans if and when we do get into a commuter car type of application.

Battery companies have been working for at least 20 years on ways to minimize or eliminate the evolution of hydrogen during the charging of the battery, which is where the danger from an explosion comes from.

Chloride in England and Chloride Silent Power in the United States did a lot of work with Lucas 15 years ago on batteries that were either sealed, self-contained, or automatically watered, things of this sort to minimize maintenance and minimize the danger of any untoward event such as a hydrogen pocket being formed and igniting.

I think in keeping with the general progress in consumer product safety and what not, those efforts will continue and those problems will be resolved through the application of suitable technology.

The other question related to safety in general, and if I might quickly expand on it, is the performance of the battery pack in the event of a collision. We will be, as I mentioned, taking the concept vehicles that were produced this summer and testing them to see that they comply with all of the Federal motor vehicle safety standards the same as any other vehicle.

Mr. LEWIS. Thank you.

Thank you, Mr. Chairman.

Mr. VALENTINE. Mr. Campbell?

Mr. CAMPBELL. Thank you, Mr. Chairman.

Dr. Mannella, I am real glad you are here.

Dr. MANNELLA. Thank you. I am real glad you are here too.

Mr. CAMPBELL. And I am real glad everybody is from Palo Alto, the center of the universe.

I appreciate your testimony, and I would like, if I may, to ask for an update on the international situation in the development of this vehicle.

I am concerned about us falling behind in this technology vis-a-vis some of our European competitors. Your testimony particularly triggered my thoughts on that dealing with the Griffon Manufacturing in the United Kingdom.

Would you be kind enough to give us an update on what other developed economies are doing in this field? Where do we stand in the competitive world on this?

Dr. MANNELLA. Electric vehicles have probably in widespread use in Europe for quite a few years. There is a couple of reasons for it. One is that the price of liquid fuel has generally always been higher in European countries than it has been in the United States. So, alternatives were encouraged.

Another reason is that European countries tend to be quite compact. There are very few countries like the United States where we have a vehicle that we expect to drive to work in one day and then drive to Palo Alto next week if the urge sets upon us.

So, there have been quite a few impressive developments in electric vehicles, and the ones that I am most particularly familiar with are in England, where Lucas and Chloride have developed a club van. The Royal mail was delivered in London for a number of years with electric vans.

It is my impression, not having been there recently to get a firsthand update, that with the development and the achievement and the experience that we have learned from Griffon, with the development of the G-van and the advent of the TEVAN, which will all occur within about the next 12 to 15 months, that we will at least be at a par if not somewhat ahead of those activities.

Mr. CAMPBELL. I am glad to hear that.

I would like to follow up with a question dealing with the United States industrial base and willingness to commit to this. In your testimony you mentioned General Motors, Chrysler, and Ford being the three manufacturers.

The question I would like to put to you is is there a need—I anticipate the answer will be in the affirmative, but I want to ask the question this way—is there a need for the Government to be involved in subsidizing this sort of research, given that the Big Three are involved in it already and that this is the sort of thing which eventually ought to be a commercially viable vehicle or we should not be doing it?

Dr. MANNELLA. Certainly. If you look at a continuum from basic research going all the way out to commercialization, the Government role disappears at some point in that continuum. The question that is always challenging is where exactly does the Government role fade out.

There is no doubt that the commercialization of this product can only be done by American industry and probably only by the American automotive industry. The electric utilities are not going to commercialize this product.

We would like to think that we are a bit of a catalyst in that we are helping the process along. But it is going to take billions of dollars to arrive at a fully commercialized electric vehicle article of commerce.

I think at the stage where we are in now, where one has to underwrite the development of high-risk items such as high-performance batteries when we are talking about developing very advanced propulsion systems in a few vehicles, which are expensive on a per-vehicle basis because of the small number and you have to test these and collect data and you have to operate them in an urban environment in order to establish what the base performance is and to eliminate some of the risks, that that is an appropriate role for the Federal Government.

Mr. CAMPBELL. I have one other question, with the chairman's permission, that deals with the implementation of this through the American industrial base.

If we were to change our antitrust laws in such a way as to permit General Motors, Ford, and Chrysler to collaborate—and this is a difficult question; it is hypothetical—but if we were to permit that, would you expect that this research could be undertaken by the automotive manufacturers on their own as opposed to going through EPRI or going through the Federal Government agency?

Dr. MANNELLA. My best answer to that would be that I think the thing that inhibits, if indeed it does inhibit, greater participation by the automotive industry and the suppliers and what not is that the market is unclear. I think that if and when it begins to look like there really is a viable market, then the American entrepreneurial spirit can be in play and what not. Then I think they will get involved to the maximum extent possible.

Mr. CAMPBELL. Mr. Chairman, that concludes my questions. I do want to commend you for holding these hearings.

And if I may just add a word of congratulations to the sort of work that EPRI is doing. I think it is a model of collaboration between industry and Government and anyone familiar with its activities would hold it up as such. And I thank Dr. Mannella.

Dr. MANNELLA. You are quite welcome.

Mr. VALENTINE. Thank you, sir.

Thank you, Doctor.

Mr. VALENTINE. Do you have any more questions? Does any other member have anything for the good of the record?

[No response.]

Mr. VALENTINE. A motion has been made and seconded that the committee will now stand in recess.

[Whereupon, at 5:00 p.m., the subcommittee was adjourned.]

APPENDIX

Testimony Submitted
to the
House Science, Space and Technology Committee
Subcommittee on Transportation, Aviation and Materials

March 31, 1989

This statement is submitted on behalf of the Southern California Edison Company, the Detroit Edison Company, the Los Angeles Department of Water and Power, The Southern Company and the Edison Electric Institute. We appreciate this opportunity to suggest to the Subcommittee an initiative to advance the prospects for commercialization of electric vehicles. This statement outlines for the Subcommittee's consideration a private sector/government cost-shared evaluation program designed to accelerate the introduction of electric-powered vans into the commercial fleets of users located in major urban areas, which will result in significant benefits to air quality and reduced oil imports. We also wish to express our support for continued funding for the Department of Energy's Site Operators Users Task Force.

For a number of years, the federal government, through the Department of Energy's Electric and Hybrid Vehicle Research and Development program, has supported research designed to reduce the technological obstacles to commercial use of electric vehicles (EVs). The electric utility industry has been a willing partner in this effort, committing time and resources to this important program.

We are close to the point of overcoming some of our most significant obstacles -- vehicle availability and a public perception of electric vehicles as slow-moving, enlarged golf carts. The technology available today can produce vehicles with acceptable performance, including the distance a vehicle can travel between battery recharging. The range of electric-powered vans ready for production in 1990, after completion of required highway safety tests this year, is estimated to be at least 60 miles in stop-and-go city driving, increasing to as much as 90 miles at constant speeds. The range of the vehicles will continue to increase as battery development advances. Also, operation and maintenance costs of EVs are lower than internal-combustion engine vehicles.

Unfortunately, the production of vehicles by major automotive manufacturers has lagged behind rapidly advancing technological developments. Introduction of the G-van, which is modeled on the General Motors gasoline-powered van, represents a near-term opportunity to make very significant progress toward commercial acceptance of EVs. The first point of market penetration for EVs will be in fleet operations in urban areas, where the current 60 mile range of the vehicle is sufficient. Importantly, these are, in many instances, just the areas that due to deteriorating air quality have the greatest need for a clean fuel alternative to gasoline-powered vehicles. At last report, over sixty metropolitan areas in the United States fail to meet EPA standards for ozone and carbon monoxide; these non-attainment areas would benefit greatly from the reduction in mobile source emissions that would result from conversion of existing vehicle fleets to EVs.

In addition to the environmental benefits, widespread acceptance of EVs will produce important energy savings, offering a means to lower U.S. reliance on undependable foreign sources of petroleum products. The Department of Energy has estimated that two-thirds of all U.S. petroleum usage is for transportation. The magnitude of the cumulative savings is clear: according to the Electric Power Research Institute, with over 160 million registered vehicles in the United States, substitution of only 1 percent of that total with electric vehicles would save 60,000 barrels of oil per day and reduce urban emissions by 160,000 tons per year.

In enacting the Alternate Motor Fuels Act of 1988, P.L. 100-494, Congress acknowledged that barriers continue to delay the widespread introduction of alternative fuels technologies, including electric vehicles. The Act directed the Secretary of Transportation, in consultation with the Secretary of Energy and the Administrator of the Environmental Protection Agency, to identify regulatory changes necessary to stimulate the production and commercialization of electric vehicles. This multi-disciplinary approach recognizes environmental improvements -- especially in heavily polluted urban areas that provide the rational marketplace for EVs -- which should be very important benefits from the commercialization of electric vehicle technology.

While electric vehicle technology makes sense for many reasons, the fact remains that as long as the cost of each vehicle stays very high, EVs will not achieve market penetration. Research to date has shown that fleet operators and the public generally will not commit to the use of large numbers of EVs until they are satisfied EVs are reliable and cost competitive. If EVs cannot meet transportation needs at costs roughly equivalent to gasoline-powered vehicles currently in use, fleet operators will not buy electric vehicles. Until there is a demonstrable demand for electric vehicles, manufacturers will hesitate to commit the funds required to complete technology development, vehicle validation and establishment of large-scale manufacturing facilities.

The last step before commercialization -- achieving market penetration and ultimate commercial acceptance of EVs -- is to reduce their purchase price. Although electric vehicles are projected to be cost comparable to internal-combustion engine vehicles on a life cycle basis, this will not be realized until the production volume of the vehicles has reached an economic level. Simply stated, the more vehicles produced, the lower will be the cost per vehicle. But per-vehicle costs cannot be reduced until substantial orders are placed. Substantial orders will not be forthcoming until the viability of these vehicles in urban settings has been proven through a large-scale evaluation project.

We are at a point where the federal government, after years of effort, should expect commitments to a substantial evaluation program that would put the latest, most advanced generation of electric vehicles on the streets and roads of urban America. We are pleased to be able to report to the Subcommittee that a number of utilities are today planning to make a major commitment to such an initiative, which would emphasize private-sector cost-sharing.

The initiative under development anticipates the placement of up to 300 EVs in fleets in several urban areas in federal fiscal year 1990. The estimated cost of each vehicle is $30,000, based on an estimated production run of 500 vehicles. It is proposed that up to 300 vehicles be purchased in federal fiscal year 1990 through a cost-sharing program: a minimum of 50 percent of the cost would be borne by the utility/private sector participants, and up to a maximum of 50 percent of the cost, up to a total of $3 million, would be borne by the federal government. The utility industry will bear the responsibility for finding users for the vehicles.

This is a natural follow-on to the efforts supported by the federal government over the last several years. The proposal is in its formative stages, but we are far enough along the road to inform the Congress and ask that consideration be given to increasing appropriations for the coming fiscal year to make this program a reality. Further details on the specifics of the program will be supplied to the Subcommittee as the authorization process continues. We understand that our proposal is precariously close to missing this year's authorization cycle, and we want to assure the Congress of our determination to finalize a proposal and present a detailed plan to this Committee within a matter of weeks.

We also support continued funding in the amount of $1 million for the ongoing Site Operators Users Task Force program. The Administration's request to reduce funds from the level appropriated last year sends the wrong signal to the potential EV markets and manufacturers. This program continues to provide important test data that will be an integral part of the success of any commercialization venture, and should be fully funded in fiscal year 1990.

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